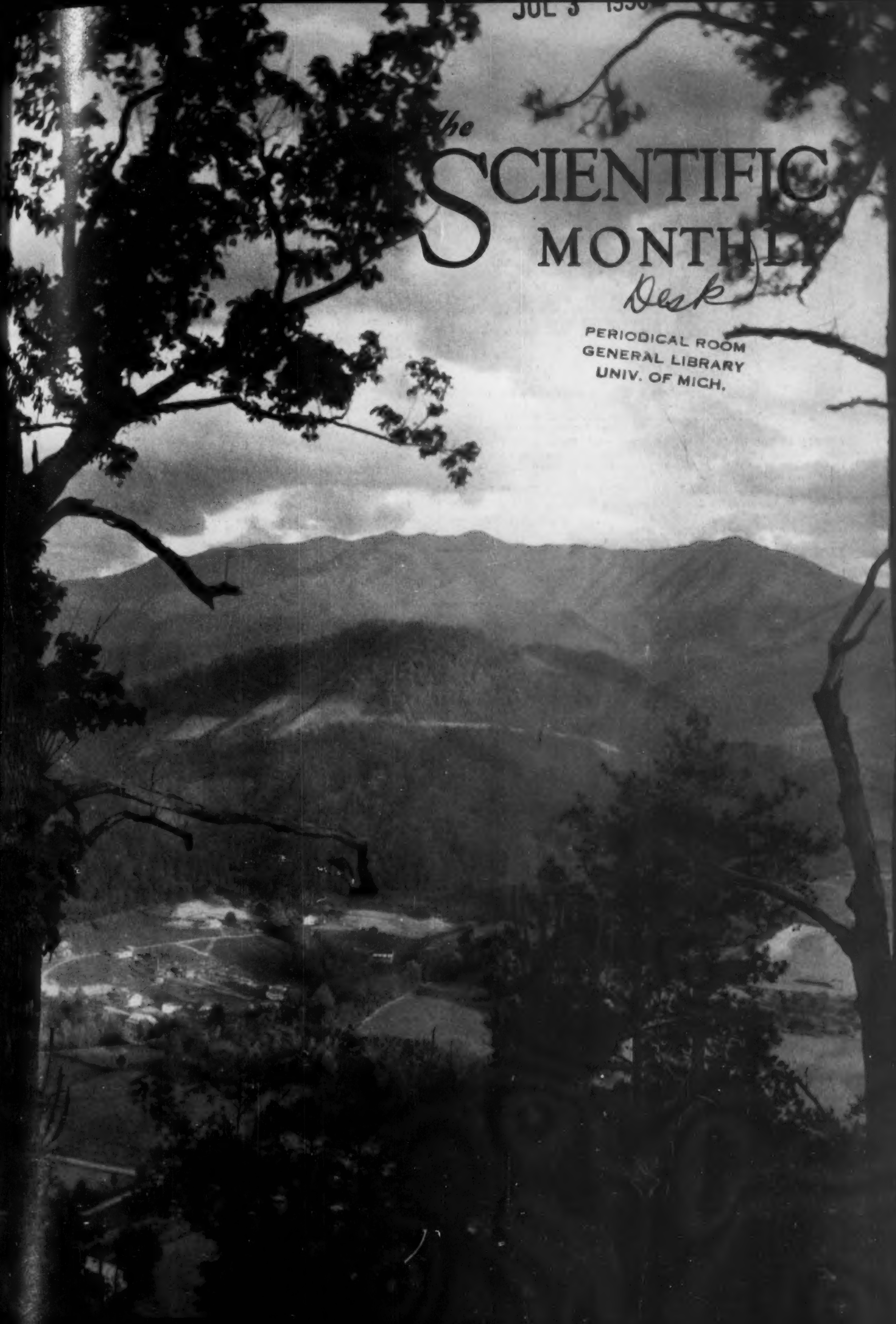
The SCIENTIFIC MONTHLY



VOL. LXXI NO. 1 JULY 1950

THE SCIENTIFIC MONTHLY

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Contents

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Science and Technology

(From the Month's News Releases)

Publications

The Building Research Advisory Board of the NRC has announced the publication of the *Proceedings* of the conference on "Weather and the Building Industry." This is a summary of work by climatologists, materials technologists, physiologists, architects, engineers, and of Weather Bureau scientists. Available in book form at $3.50; quantities at special prices.

The U. S. Geological Survey has prepared translations of six Russian articles on Soviet methods of prospecting for ores by geochemical methods. Free copies may be obtained on request to the Director, Washington 25, D. C.

Achema Year-Book, 1940–50. Herbert Bretschneider, Ed. 704 pp. Illus. Dechema Deutsche Gesellschaft für chemisches Apparatewesen E. V. Frankfurt-on-Main. Prepared for the Achema IX Exhibition and Convention for chemical apparatus, to be held in Frankfurt this month.

The Story of Cellophane, from E. I. du Pont de Nemours, tells it in pictures.

Ecological Crop Geography of Finland and Its Agro-climatic Analogues in North America, by M. Y. Nuttonson, is Study No. 10 of the International Agro-Climatological Series, American Institute of Crop Ecology.

General Aniline & Film Corporation is distributing a "College Map" giving the location of some 240 colleges in the United States. It is illustrated with etchings of American college buildings, with the Dunster Gate of Harvard University on the cover.

Thirtieth Annual Report of the National Bureau of Economic Research takes the form of a booklet on *New Facts on Business Cycles,* by the Bureau's director of research, Arthur F. Burns.

Better Dentists

The Council on Dental Education of the American Dental Association is preparing to place its dental testing program in nation-wide operation. Applicants for admission to dental schools for the 1951 fall classes will be required to take a battery of aptitude tests in all but two dental schools of the United States.

Design for Hot Weather Living

Less work for the laundress is in prospect since the development by the USDA of "CMC." The addition of a small amount of this compound to the final rinse water will make cotton fabric more resistant to soiling and permit the use of less soap. Already available to wholesalers, it is expected that it will soon be put on the market in convenient packages for home use.

Water goggles designed especially for children are called Jr. Gog. They are provided with unbreakable plastic lenses, inner sealing rings, and adjustable head strap. Made of natural rubber in sea-green, they retail at 69 cents. And, for a place to use the goggles, there is a colorful vinylite plastic sheeting swimming pool large enough to cool off the entire family on hot days.

You save little time in cooking by prethawing small amounts of frozen meat, says the ONR. Tests conducted for the Navy by Cornell University revealed also that palatability is little affected, and in some cases the judges actually preferred the unthawed meat.

Crab grass, lawn enemy No. 1, may now be destroyed without harm to other grasses, according to news from O. M. Scott & Sons Company, of Marysville, Ohio. They announce the development of Scutil, a dry-applied powder, which is effective against both major varieties of crab grass if used several times in July and early August.

The Palmer DeLuxe Trailer Cooler may be used in trailer coaches, small homes, and offices. It weighs 90 pounds, is 28″ × 28″ × 22″, and will cool 2,000 cubic feet of space. No duct work is required for installation.

Stopall, a waterproofing solution containing silicones, for treating concrete and cement building blocks, will help the homeowner keep the basement dry. It can also be used to keep water out of porous stucco and sandlime brick.

For those without kitchen facilities, and for trailer owners, picnickers, and campers, Snackit, used with solid fuel tablets, offers a convenient method of cooking small quantities of food. The entire unit will fit in the glove compartment of a car.

A Venetian blind cleaner for either flat or curved slats can be used with any household cleaning detergent. Light pressure on the cleaner's spring-action, foam-rubber-covered jaws cleans both sides of the slat with a single stroke.

For Rail Fans

With more and more railroads turning to the use of diesel engines, those old-fashioned people who miss the friendly sound of the steam locomotive whistle will be glad to hear that the Baltimore & Ohio Railroad is doing something for them. Airchime, developed in Canada, produces a musical chord similar to the sound of the traditional steam whistle. In its five-chime form, it has been installed in the B & O New Columbian. Eight yard and switch diesels have been equipped with single chimes, suitable for use in urban areas.

Safety

The Port of New York Authority is installing instruments so sensitive they can detect as little as one part of carbon monoxide in a million parts of air in the ventilation system in the Holland Tunnel. In operation, air to be tested is drawn through a chamber containing Hopcalite, a catalyst developed by Johns Hopkins and University of California researchers. The resulting chemical reaction liberates heat, which is measured by a differential thermopile. This in turn energizes indicating and recording meters. None of the other common gases or vapors in the tunnel air affect operation of the instruments.

Security Roster

A list containing the names, background, and experience of the nation's top scientists has been compiled for the Army, Navy, and Air Force by the ONR. The roster will be maintained by the National Security Resources Board.

Student Flights to Europe

Those interested in studying abroad this summer might do well to investigate International Studytour Alliance plans for chartered flights to London and Paris via four-engine Douglas DC-4s. The round-trip fare is $350, airport to airport.

THE SCIENTIFIC MONTHLY

JULY 1950

Exploration of Electrostatic and Magnetic Fields

L. L. MARTON

As chief of the Electron Physics Section of the National Bureau of Standards, Dr. Marton (Sc.D., Zurich, 1924) directs the Bureau's research on the basic theory, methods, and applications of electron- and ion-beam devices, including interaction phenomena between charged particles and matter. Internationally known for his work in electron optics, particularly the development and perfection of the electron microscope, Dr. Marton joined the staff of the Bureau in 1946.

EVER since Faraday introduced, more than a century ago, the field concept for explaining the interaction between electricity and magnetism, the measurement of electric and magnetic fields has become increasingly important. Essentially, two types of information are needed to describe such fields adequately. One is a qualitative picture of the general orientation and distribution of the field; the other is the absolute value of its intensity at each point in space.

In the case of magnetic fields, qualitative effects were observed long before Faraday. Thus, from the time of earliest recorded history, we find navigators using a piece of magnetic ore to determine the direction of the earth's magnetic field. Another very simple experiment that has been known for a long time is the representation of the lines of force about a magnetized object by covering it with a sheet of paper sprinkled with iron filings. The iron filings arrange themselves in a pattern closely representing the distribution of the lines of force in the plane of the paper. With the increasing development of physics and engineering, however, more exact, quantitative methods became necessary for the description of the magnetic field distribution. At the same time a need arose for precise methods of treating the electric field of force about a charged body.

The ideal method for a complete quantitative determination of a field involving either electrostatic or electromagnetic phenomena is to calculate the intensity of the field at each point from theoretical considerations. The electrostatic field must obey Laplace's equation, which stipulates that for any given volume of free space within an electrode system as many electrostatic lines of force must leave as enter. On first consideration, this simple statement would seem to provide an easy means of arriving at the field distribution for any given system of electrodes. Actually, however, only the simplest cases, in which there is a high degree of symmetry, can be completely solved by calculation. Whenever symmetry is less pronounced, the theoretical treatment becomes far too complicated to yield an analytical expression.

Most of the experimental methods for obtaining the electric field distribution have involved the introduction of some kind of a probe into the field.

Such a probe must satisfy a number of conditions, one of the most important being that it must not disturb the field which it explores. If the field gradient is high the probe used imposes a limitation on the measuring accuracy. This size limitation is not always easy to satisfy. In fact, when the field to be explored is very small, the probe cannot be made small enough to obtain results of any value. Under these circumstances it is often advisable to make a large-scale model of the field and then explore that model with a small probe. Such large-scale models can be applied to even greater advantage by using some extremely useful analogies between the field distribution existing between charged electrodes and the current distribution in an electrolyte having similarly shaped electrodes. This latter analogy has been widely used in the past few years for exploration of practical field distributions, particularly in the design of vacuum tubes of various kinds, and has proved to be an extremely valuable tool for the production of improved designs.

Besides the experimental determinations of field distributions, there exists a number of methods which use numerical computation based on an approximation of Laplace's equation. Such numerical methods, one of them being the so-called "relaxation method," have proved highly successful for the determination of field distribution. Although they are sometimes rather laborious, they are preferred by many workers because their accuracy is mainly a matter of the time spent in computation, whereas the accuracy of the experimental methods is usually limited by various factors.

Exploration of magnetic fields is even more difficult. The powder patterns and similar methods merely give qualitative information about the orientation and distribution of the field. If we then resort to calculation, we encounter the same limitations as in the electrostatic case. Experimental determinations using large-scale models are less apt to be useful here since the laws of similitude are not always satisfied. For example, when saturation phenomena occur, it is hard to account for them by reference to any large-scale analogy. This means we have to explore the field "as is," and thus the probe-size limitation becomes serious.

In spite of the many years spent on the determination of field distributions, there are several categories of fields which have remained until now practically inaccessible to exploration. In most cases these fields could not be treated mathematically because of the complexity of the phenomena involved. In other cases, different theories gave widely divergent results, depending on what primary assumptions were made for the calculation. Experimental attempts to measure such fields usually failed because of the size of the probe involved which either disturbed the field to be measured or was not sufficiently sensitive.

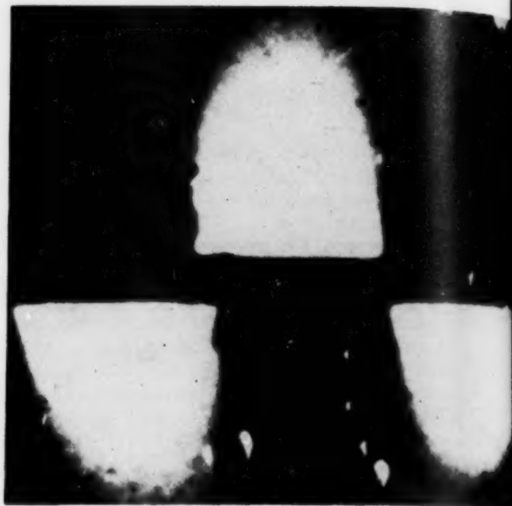


FIG. 1. Schlieren pattern of field about a magnetized wi

Obviously, the next step in the development of better methods of field exploration was the reduction of the probe size. The probes that had been used—small coils, metal conductor samples, heated wires—could not be reduced beyond a certain limit. A radical departure was therefore needed and such a radical departure was provided by the use of the elementary charge of electricity, the electron, as a probe.

The use of a charged particle for the exploration of a field is not entirely new. When Rutherford measured, almost forty years ago, the distribution of the directions of alpha particles scattered by a thin foil, he was essentially using a charged particle for the determination of the field distribution around the atomic nucleus. Another example is the even earlier experiment of J. J. Thomson, in which he attempted to measure the field distribution in a gas discharge by shooting a cathode-ray beam through it. Since those two early experiments, efforts have been made to transform the method into a more generally usable one; but until now its usefulness has been limited to very special situations, chiefly because the beam that was used was a relatively narrow pencil which varied over the length of the apparatus. Such an electron beam tends to spread because of the mutual repulsion of the charges, and the accuracy of the results is correspondingly reduced. A method was therefore required which would keep the electron beam from spreading and yet would provide information on the entire field without regard to the size of the beam used for the experiment.

The obvious answer was to make use of our present knowledge of electron-optical systems. This was done at the National Bureau of Standards, resulting in the development of two techniques—the electron-optical Schlieren method and the electron-optical shadow method—both of which give quantitative information on fields of very small dimensions.

The Schlieren method used in light optics involves the formation of an image of a light source on a convenient stop which intercepts all direct rays. If, in the space between the source and lens, there is a variation of the index of refraction, an image of that inhomogeneity will then be produced by means of the same lens on a screen placed at the proper distance beyond the stop. Thus a dark-field image of the variation in optical density of the refractive medium is obtained.

In the electron-optical analogy to this experiment, the light source is replaced by an electron gun, the glass lens by an electron lens (usually a magnetic coil), and the inhomogeneity of the light index of refraction by an inhomogeneity of the electromagnetic index of refraction. Since electrostatic or magnetic fields constitute variations of the electromagnetic index of refraction, they can be made visible in this way. The very first electron-optical Schlieren experiment that was carried out was immediately successful. Figure 1 shows a "Schlieren" pattern obtained in observation of a very thin recording wire magnetized in evenly spaced short pulses.

By photographing the Schlieren pattern, a qualitative picture of the field distribution is immediately obtained. This result is similar to the powder patterns in that it shows the extent of the field and its location with respect to the magnetized wire, but it can be used for much smaller fields than can the powder patterns.

A second advantage of the Schlieren method lies in its amenability to quantitative treatment. In the powder patterns we can merely estimate the field strength from the relative crowding of the lines of force at certain parts of the pattern; there is no way of obtaining really quantitative information from the technique. On the other hand, once images of the field have been obtained by the Schlieren method, the actual intensity in the neighborhood of the sample can be computed to a good approximation from the intensity distribution of the pattern or from the apparent displacement of a deflected image.

The difficulties involved in the quantitative application of the Schlieren method are far from negligible, however. First of all, an intensity distribution is not easily determined unless there is some direct means for measuring the intensity across the image. Whenever the image is recorded photographically, the intensity distribution is modified by each step in the photographic process, and it is hard to account for the modifications thus introduced. Moreover, the intensity distribution in the photograph depends also on the aperture size of the lens, the size of the obstacle for intercepting all direct rays, and other variable factors. Thus, al-

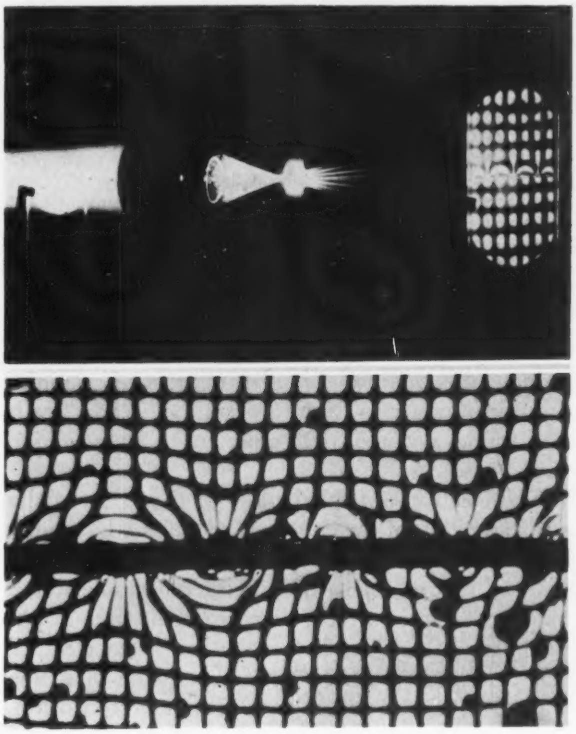


FIG. 2. Above: The electron-optical shadow method is illustrated by an analogous experiment in light optics. A mounted lens system (left) converges light from a distant source to form a reduced image of the source at a point ahead of a wire screen (center). A magnified shadow image of the wire screen is then formed (right) by projection from the reduced image. If the lower half of the light beam is intercepted by a piece of plastic deformed along its edge in such a way as to deflect some of the light rays, the result is a distortion of the corresponding part of the shadow network on the screen. In the electron-optical shadow method, the glass lens system is replaced by an electron lens, and the distorted plastic by a magnetic or electric field.

Below: Photograph of a typical pattern. Superposed on the image of a magnetic recording wire is the electron shadow of a fine wire mesh placed just beyond the back focus of an electron lens. From the displacement and reduced magnification of a selected part of the mesh, the absolute value of the magnetic field intensity at a corresponding point in the field can be accurately computed.

These two photographs were together awarded first prize in the Third Annual International Photography-in-Science Salon, sponsored by THE SCIENTIFIC MONTHLY and the Smithsonian Institution.

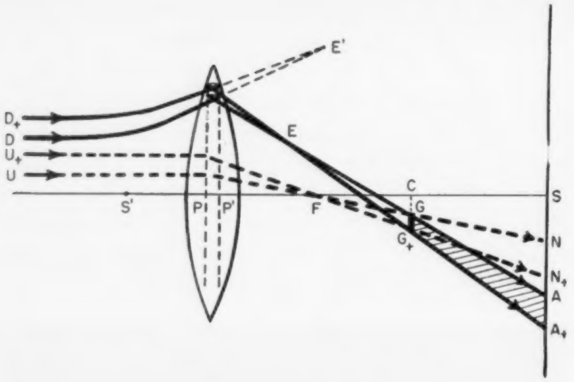


FIG. 3. Electron-optical diagram of shadow method. In the absence of a deflecting magnetic field, a parallel incident beam of electrons (dashed rays U, $U+$) converges to the focus F of the electron lens and then diverges past the thin obstruction $GG+$, which casts a shadow $NN+$ on the fluorescent screen S. However, when a deflecting field is placed in the midst of the incident beam, a different pair of rays ($D, D+$) determines the shadow boundary. The crossover point is displaced from F to some point E, and the resulting displacement of the shadow $NN+$ to the position $AA+$ may then be measured and substituted into theoretical formulas to obtain the field strength.

though this method seemed to offer a definite promise of quantitative interpretation, in practice it was found not too well adapted to quantitative work.

The electron-optical shadow method, essentially a modification of the Schlieren technique but much better adapted to quantitative treatment, was discovered in the course of a Schlieren study of the magnetization of a recording wire. The present applications of this method make use of an electron lens system to produce a shadow image of a fine wire mesh placed in the path of an electron beam. From the distortion in the shadow network caused by deflection of the electrons as they pass through the field under study, accurate values of field strength are computed (Fig. 2).

In practice, the recording wire—or other object to be studied—is placed between an electron source and the system of electron lenses. The lens system focuses the electron beam to form an image of the wire on a fluorescent screen. By placing a wire mesh of known gauge just beyond the back focus of the lens system, a shadow image of the mesh is superposed on the image of the wire. This shadow image is formed by projection from the virtual source provided by the reduced image of the source of electrons. The portions of the shadow network adjacent on the screen to magnetized regions of the recording wire are then found to show considerable distortion (Fig. 3).

Theoretical analysis of this effect has shown that the distortion of the shadow image is due to the deflection of the electron beam by the field of the recording wire at each magnetized region. The result is a corresponding displacement of the reduced image of the electron source. This displaced image of the source, acting now as a virtual source, projects on the fluorescent screen a shadow image of the network, which in general is displaced and changed in size because of the displacement, both lateral and axial, of the virtual source. Obviously, the displacement and change in size of the shadow image at any point depend on the strength of the field of the magnetized wire at a corresponding point.

Formulas have been derived by S. H. Lachenbruch, of the Bureau staff, which permit the calculation of consistent absolute values of field strength in magnetic or electric fields of various geometries from experimental measurements of the position of the wire mesh, the displacement and magnification of its shadow image, and the known constants of the apparatus. In this way, quantitative data on the field distribution shown in Figure 2 were obtained. The shadow method is thus of far greater utility for quantitative work than the Schlieren method, since the image displacement and magnification can be measured much more accurately than can the intensity distribution across the Schlieren pattern on a photographic plate.

Perhaps the greatest value of the electron-optical shadow method lies in its utility for exploring complex electric and magnetic fields of extremely small dimensions or in which a probe of size greater than the electron would disturb the field under study. In the past, calculations of the field intensity at a point have been limited to those special cases in which the geometry of the field exhibits a high degree of symmetry. The shadow technique now provides data for accurate calculation of the absolute value of the field intensity in selected planes about a specimen of any size or shape without altering or disturbing the field. The method is thus well adapted to investigation of the fundamental nature of ferromagnetism.

Many phenomena of magnetism defied explanation for a long time, until P. Weiss advanced the domain concept of magnetization. According to this concept, a specimen of ferromagnetic material, such as iron, cobalt, or nickel, consists of a number of small regions, or domains, each spontaneously magnetized to the saturation point. Before a piece of iron or steel is magnetized, the elementary magnets are oriented more or less at random throughout the material. But when a bar of metal is magnetized, the tiny individual magnets tend to line up parallel to each other. Study of the ferromagnetic domains

is thus basic to an understanding of the fundamental nature of magnetism.

The existence of ferromagnetic domains has been demonstrated in patterns obtained with colloidal powders using the principle of the iron filing patterns. In this way it has been found that the domains differ somewhat, depending on the methods used in preparing the specimen. For example, if the surface of the specimen has been finished mechanically, comparatively small domains, usually known as "Bitter domains," will be produced. The larger "Weiss domains" are observed only after the surface is prepared by chemical treatment and is thus free of any mechanical deformation. Whichever type of domain is present, however, the field produced at the domain boundaries is necessarily very localized and extends into a very limited part of the surrounding space. It is obvious that the conventional probes used for measuring magnetic field distribution are inadequate for measurement of such fields, and if we wish to have quantitative information on them, we must rely on an electron-optical technique such as the Schlieren or the shadow method.

Figure 4 shows a Schlieren pattern obtained at the National Bureau of Standards in the first attempt at electron-optical observation of ferromagnetic domains. Thin laminar steel provided with a fine edge was first magnetized to saturation and then inserted in the path of an electron beam stopped off so that only the electrons scattered or deflected by the thin edge of the specimen were able to reach the photographic plate. The image thus consists of a bright line interrupted at irregular intervals by faint patterns due to the deflection of electrons by the fringe fields of the ferromagnetic domains.

This pattern presents an interesting picture of the fringe fields, but it has two disadvantages for the study of ferromagnetic domains. First of all, it is a Schlieren pattern, and is therefore difficult to evaluate quantitatively. Second, the sample was prepared by mechanical polishing, so that the pattern corresponds more closely to the Bitter domains than to the Weiss domains, in which we are primarily interested. Later, when the shadow method was developed, it was applied to a single large crystal of cobalt, which was obtained through the courtesy of the Bell Telephone Laboratories. This crystal constitutes a much better specimen for study of the domains (Fig. 5). The quantitative interpretation of the pattern obtained with the cobalt crystal is much more difficult than that provided by a magnetized wire. In the case of the magnetized wire there is a degree of symmetry around the axis of the wire which simplifies calculation. No such symmetry is present about the domain boundary in the cobalt crystal, and the calculations leading to the absolute value of the field are much more complicated. Although these calculations are not yet entirely complete, a preliminary figure giving the order of magnitude of the field has been obtained: in the mid-plane of a "domain wall" and at a distance of 5 microns from the surface of the specimen, the field is about 3,000 gausses.

In recent years it has been found that "ferroelectric domains" can exist in high-dielectric substances like barium titanate. These domains represent a localization of electric charge in electrical nonconductors and analogous to the ferromagnetic domains. They have electric fringe fields about them similar in many ways to the fringe fields about magnetic domains.

The first attempts at observation of the ferroelectric fringe fields in barium titanate by means of the shadow method failed because of a rather obvious difficulty: the electron beam charged the barium titanate crystals, and the resulting pattern was entirely due to the field produced by the accumulated charge, which completely masked the effect of the ferroelectric domains. An illustration of such a field is of interest, however, if for no other reason than the aesthetic value of the pattern it produces (Fig. 6).

Once the source of difficulty in the observation of the ferroelectric fringe fields was recognized, it was possible to compensate for the effect of the electron beam and to obtain patterns due only to

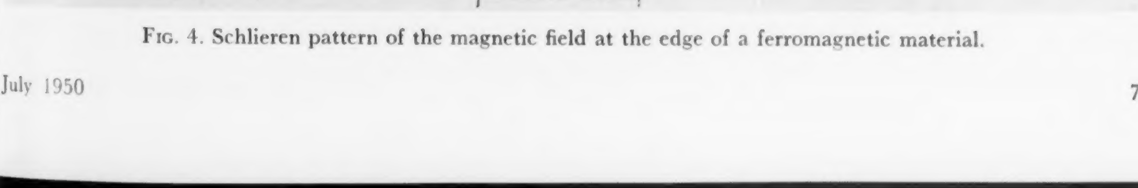


FIG. 4. Schlieren pattern of the magnetic field at the edge of a ferromagnetic material.

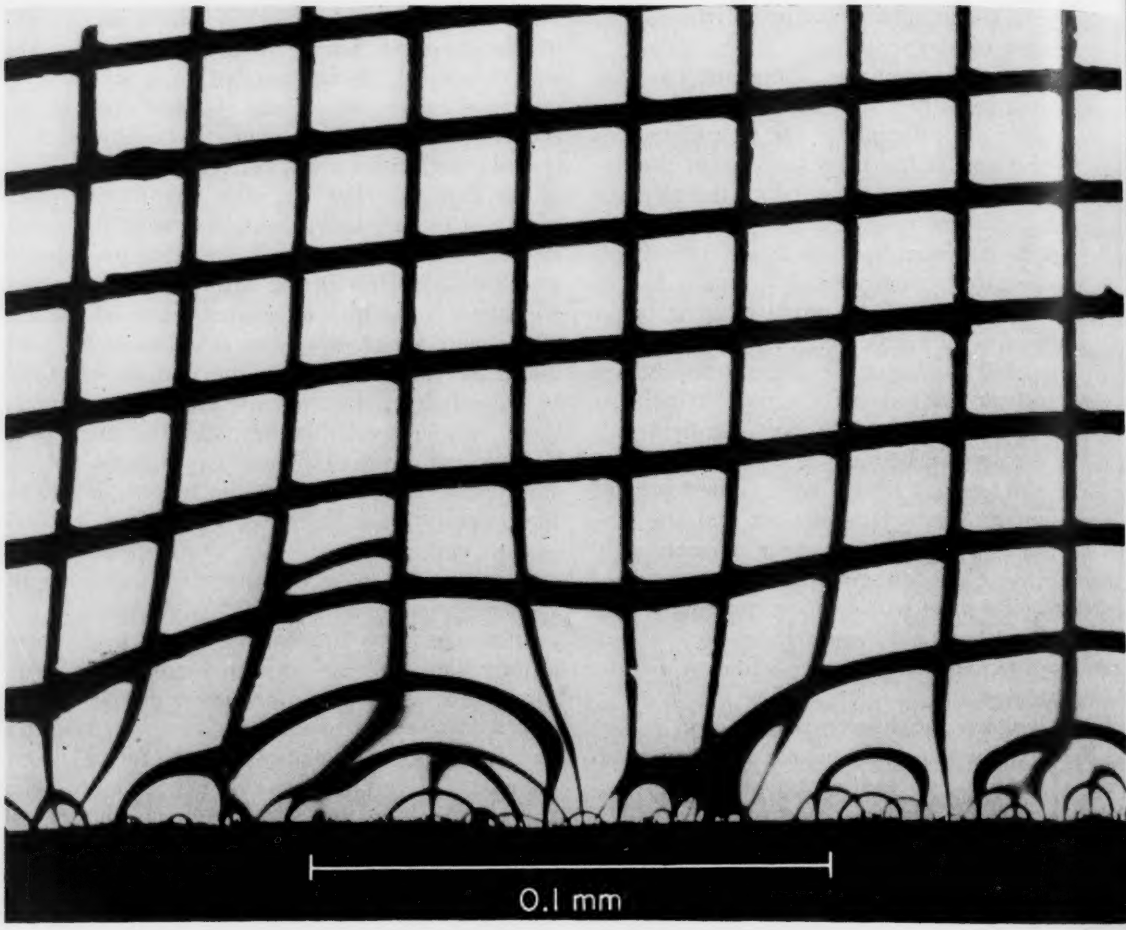


FIG. 5. Shadow pattern of the magnetic field at the edge of a cobalt crystal, showing large domain structure.

the fringe fields of the ferroelectric domains. As shown in Figure 7, they are much weaker than the field due to the electron beam.

In addition to its use in studying the basic properties of magnetic and dielectric materials, the electron-optical shadow method is expected to provide a powerful tool for broadening present knowledge concerning a number of phenomena of interest to the engineer and the physicist. One field having extensive application in electronics is the exploration of the space-charge phenomena. Although the electric charge on a conductor is usually regarded as confined to an infinitely thin layer on the surface, streams of electrons or positive ions may occupy sizable regions within a vacuum tube, to the virtual exclusion of electricity of opposite sign. The cloud of electric charge thus formed is known as a space charge and may have considerable effect on the performance of the tube. At present a better knowledge of space charges is badly needed, and the Bureau is working on the problem of the space-charge distribution in several kinds of apparatus employing electron beams. Use of the method with a pulsed electron source for the stroboscopic study of fields that vary with time is also under study.

The magnetron, a vacuum tube widely used for generating power at microwave frequencies, has a very high space-charge density which is known to have an important bearing on its performance. Very little is actually known, however, concerning the electric-field distribution and space-charge configuration within the magnetron. Although the problem has been investigated theoretically by many workers, the formidable mathematics involved have not permitted an exact solution, and the various simplifications of the theory that have been suggested have led to widely divergent results. Attempts at direct measurement have also proved unsuccessful because the very critical symmetry of the field under study was disturbed. A promising approach to the problem has now been provided by the method recently developed at the National Bureau of Standards. This method, a modification of the electron-optical shadow technique, uses a

agnetic lens to produce shadow images of two fine re screens placed at either end of the magnetron the path of an electron beam. Then, from the distortion in the shadow network (Fig. 8) caused by deflection of the electron rays as they pass through the magnetron field, the radial electric field

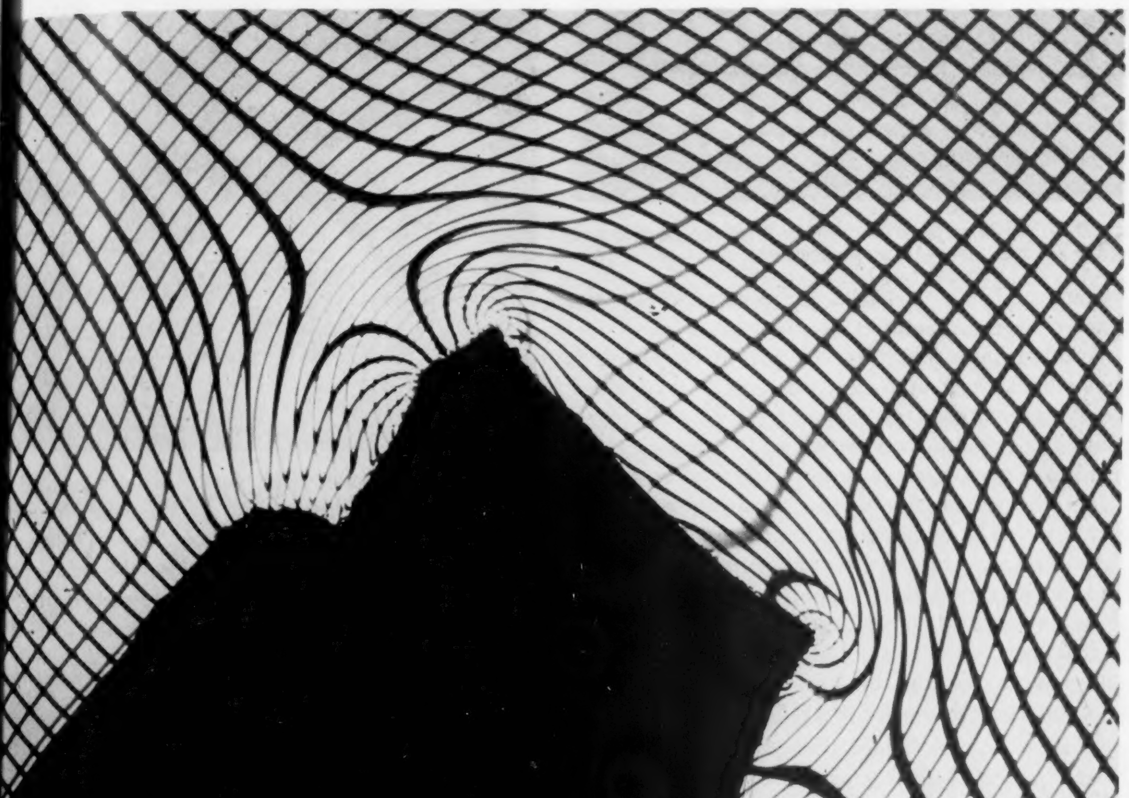


FIG. 6. The electric field about a charged crystal of barium titanate provides this striking pattern when studied by the electron-optical shadow method. The distorted shadow image of a wire mesh is superposed on the image of the crystal (center) and its 0.010-inch tungsten-wire support.

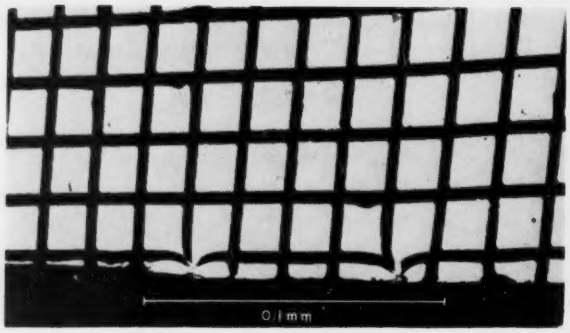


FIG. 7. Shadow pattern showing ferroelectric domains at the edge of a barium titanate crystal.

is computed. These results are used to obtain the space-charge distribution.

Another interesting subject for investigation is the field distribution in electromagnetic waveguides, cavity resonators, and similar types of "electronic plumbing" used as conductors and circuit elements in ultra-high-frequency radar and communication. Often the geometry of these arrangements is too complicated to be expressed mathematically. Thus the electronics engineer, having in many cases only an intuitive picture of the field distribution at junctions and elbows of the guide, must rely on empirical methods in designing waveguide techniques and equipment. By the use of suitable auxiliary techniques, it is hoped that the shadow method may be adapted to the calculation of field intensities in regions of a guide that are not at present susceptible to analytical treatment.

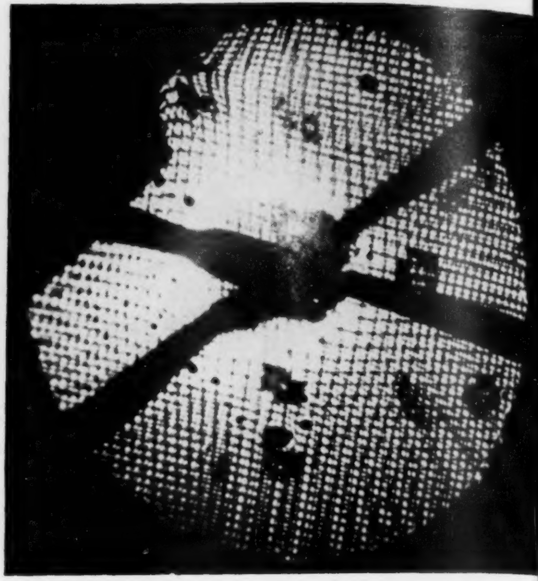


FIG. 8. Double-wire mesh shadow pattern of the electric field in a magnetron. A space-charge ring (light area) is clearly visible in the central region.

PICTURE CREDITS: Figures 1, 3, 5, and 6, courtesy *Journal of Applied Physics*; Figure 4, courtesy *Physical Review*.

LIGHT

All color is to light as pitch to sound.
The human eye can see one octave's light,
But those that soar past violet abound—
And octaves still exist, though not to sight,
Below the red. And these, the rays not seen,
Can change our color, probe the not-yet-sure,
Project our inner secrets on a screen,
Can warm the earth, can kill or swiftly cure.

Pit light waves against light. You may perceive
The trough of one, the other's crest concur.
So, from the joining, there may weirdly weave
A darkness black and soft as inky fur.
How dauntless man who from his tiny shore
Sets forth in endless quest of knowing more!

VIRGINIA SCOTT MINER

Descartes' Role in the History of Science

LAURENCE J. LAFLEUR

Formerly on the teaching staff of Antioch College, Dr. Lafleur (Ph.D., Cornell, 1931) has recently joined the Department of Philosophy and Religion at Florida State University. His article is based on a paper read at a joint meeting of the Philosophy of Science Association, the American Philosophical Association, and Section L at the 1949 Annual Meeting of the AAAS in New York City.

DESCARTES is one of the best known men in our intellectual history, yet our appreciation of him is still not adequate. He is known primarily as a philosopher, secondly as a mathematician, and in the history of science we usually assume that his importance is practically confined to this. To be sure, this is in itself no trivial matter, since these influences are widespread and permeating. First, Descartes' empiricism was widely influential in promoting the change from the typical mediaeval to the typical modern attitude. Then his rationalism and scientific optimism helped set a pattern which lasted for two and a half centuries. This was the assumption that ultimate truth can be achieved and the world thereby turned into a Utopia. He insisted that all laws must be universal and eventually derivable from a single basic law of the universe. This implied that scientific progress is to be achieved not only or even primarily by learning new facts, but rather by the device of consolidating laws already achieved in different fields, as, for example, Newton combined Galileo's laws of falling bodies with Kepler's laws of planetary motions. But the first outstanding achievement in combining laws was that of Descartes himself when he synthesized the methods of algebra and geometry in the new field of analytic geometry. Descartes' approach to philosophy through the analysis of the self led directly to the development of association psychology in England, and his influence may be traced in several contemporary schools of psychology. Finally, Descartes' metaphysical dualism produced results of the deepest significance in modern science. The assumption that there are two entities, mind and matter, completely distinct in their characteristics, when coupled with the assumption that natural laws are intelligible—i.e., that it should be evident that a cause is related to the effect it produces—made it evident that mind and matter are not merely distinct, but also unrelated. The world thus falls into unconnected halves. This situation is philosophically intolerable, and it has produced effort after effort to resolve it, including Occasionalism, Epiphenomenalism, Neutral Monism, and many forms of Idealism. In science, since most of the interest and all the prestige were confined to the physical sciences, the compartmentation of the world through Cartesian dualism left the scientist committed to physical reality at the expense of mental reality, and the denial of the importance, and perhaps even of the existence, of mental phenomena followed. The results of this attitude are not only manifest in the history of science, but the attitude continues to confuse contemporary scientists in several fields.

So much for the influence of Descartes the philosopher. Descartes the mathematician was obviously important: the development of analytic geometry leads naturally and inevitably to the calculus, and the tools are basic not only in the development but even in the conceptions of modern physics.

When we turn to Descartes the scientist, we find that it has become customary to speak of his work as speculative and deductive, and to criticize him for failing to make more experiments and offer fewer unverified theories. There is just enough truth in these criticisms for us to understand how they came to be made, and enough misrepresentation to make us reject them as unjustified.

First of all, Descartes showed, both in his philosophy and in his behavior, that he was a good experimentalist. One reads occasionally, in his works, a description of a particular experiment: much

more frequently he merely states that if the reader will do so and so, he will observe such and such. And, except for a few cases where Descartes is clearly trying to predict something which he could not have observed, his facts are always correct. Now when we find in his work a number of theories that appear to us to be approximately correct, a larger number that appear to us to be mistaken, and a few that appear absurd—all of which are used to deduce certain conclusions which on observation turn out to be facts—we may safely conclude that we are not dealing with deduction but with explanation. The facts must have been determined experimentally, presumably by Descartes, since he suggested in the *Discourse on Method* (p. 73) that he must do over again all experiments originally performed by others, and his theories therefore represent hypotheses intended to explain the facts and not a priori givens from which the facts are deduced.

But to say that Descartes was a confirmed empiricist and experimenter is not to deny that there are differences between his empiricism and that of modern science. The less important of two differences that we may point out consists of the limitations he may have imposed upon the inductive method, the more important is a logic of discrete possibilities which Descartes shared with Bacon and Mill.

Descartes' contributions to the several sciences are important, and almost entirely unrecognized at the present time. To save time, I shall confine my attention to his work in the physical sciences presented in the volume published in 1637. This is not too great a limitation, since his later work is distinctly inferior to his earlier writings, and since his biological and physiological theories are both better known and less valuable than the ones we shall consider.

Descartes proposed the theory that light is a vibration in some material, for the most part in what we may recognize as the "ether." That this doctrine is not generally ascribed to him appears to be due to the great prominence of Newton's corpuscular theory that entered the field a generation later and held it almost uncontested for two centuries. Descartes is sometimes erroneously credited with the law of reflection of light, to which he may have added the rule for reflection from a curved surface, and he is commonly, and I think correctly, credited with the law of sines in refraction. It appears that Willebrord Snell had achieved something like the law of refraction before Descartes did, but he did not publish his results, and we only have the report of two scientists that the law is to be found in his private papers. Even if the law was adequately presented there, which we do not know, it would hardly be sufficient grounds for denying credit to Descartes. It has been suggested that Descartes took his principle from Snell. This is possible, but there is no evidence for it. It should be remembered that our present ideas concerning what we might call private property in credit for ideas are largely peculiar to our age: Descartes himself is not concerned with such credit. He wrote: "I do not claim, either, that I am original in any of these ideas, but only that I have never accepted them because they were maintained by others, nor because they were not so maintained, but only because reason persuaded me of their truth" (*Method*, p. 77).

Both the laws of reflection and of refraction were derived by him from an argument which can be recognized as the analysis of motion into two vector components at right angles to each other. In Discourse Two of *Dioptrics*, Descartes analyzes the motion of a tennis ball striking a hard surface and a resisting surface such as a net or the surface of water by considering that its motion may be resolved into a vector component parallel to the surface, which is unaffected in the process, and a component perpendicular to the surface, which is reversed in the case of a bouncing ball or reflected light, or reduced in quantity when encountering a resisting but penetrable surface, such as the net or the surface of a body of water. The case of light differs somewhat from that of the ball since the two determining factors are that the parallel vector remains unaffected and that the total velocity is changed to that typical of the new medium. Incidentally, the notion that light is instantaneous, commonly attributed to Descartes, is at variance with several details of his thought, and is probably due to his use of a phrase which can be interpreted as meaning either "instantaneously" or "very rapidly." He surmised that the index of refraction was equal to the ratio of the velocities of light in the two media concerned, although he erroneously supposed, after the analogy of sound, that the velocity of light was greater in the denser medium. His error here was corrected by Fermat. Note, however, that in the absence of techniques for measuring the velocity of light in different media, all that Descartes could determine experimentally was that the ratio of the sines, or the index of refraction, was constant for a given pair of media, and that the product of the indices for any series of substances beginning and ending with the same substance must be unity. That the index should be also the ratio of two velocities was empirically unverifiable in

Descartes' time, and it is not particularly significant that Descartes guessed this fact correctly, nor that he used the inverse of the true relationship.

Descartes gave an analysis of the rainbow which is a model of scientific procedure and the only reasonably complete example we have which shows the development of his thought in dealing with a scientific problem. In the Eighth Discourse of *Meteorology,* Descartes relates how he decided that the phenomenon of the rainbow depended upon raindrops in the air, since it could be observed in fountains as well as in clouds, and that the size of the drops was unimportant. He therefore procured a spherical glass vessel and filled it with water, and found that it sent red light to his eye when viewed at an angle of 42° from the line from the sun to the globe. If the angle was made larger, the color disappeared; if smaller, other colors were observed. By introducing obstacles into the path of the light, it was possible to determine its precise course: it entered the upper part of the globe, was refracted to the opposite side, there reflected to the lower side and refracted to the eye. Another less vivid red becomes apparent at 52°, and the other colors at greater angles. This light enters the lower part of the globe, is refracted to the opposite side, then is reflected to the upper side and reflected again to the near side before being refracted to the observer. Descartes took the index of refraction of water with respect to air to be 187/250, from which he calculated the angles of the first and second rainbows to be 41.47° and 51.37°. As there are elements of uncertainty in the calculation, this is in close enough agreement with his own observations, which were much more accurate than earlier ones. The previously accepted angles were 45° and 56°. Descartes pointed out that there would be some further variations if the drops were not precisely round. He had heard of a third rainbow being sometimes visible, but erroneously ascribed it to refraction in hail. He correctly described and explained the phenomenon of a reflection rainbow, which he had not seen, and pointed out that a rainbow may appear as a complete circle.

Not all the credit for the explanation of the rainbow can be given to Descartes, for the subject had been much discussed previously. Macrolycus, in particular, had correctly assumed that the first rainbow was due to two refractions and one reflection, and the second to two of each. But Descartes was the first to give the complete fundamental explanation, the first to report the angles correctly, the first to produce experimental verification, and the first to calculate the theoretical angles.

It should also be noted that Descartes is here touching upon the analysis of white light, credit for which is commonly given to Newton. And Descartes did in fact precede Newton in that famous experiment wherein Newton broke up white light into colors and then reconstituted them as white light. For Descartes says that what he did with the globe can also be done with a triangular prism: he let light pass perpendicularly through the hypotenuse and refracted it through one of the other sides. Either one of the surfaces involved is to be entirely covered except for a slit: wherein we recognize the first slit spectroscope. Descartes thus concluded that the division of white light into colors is not a property of water, but is the result of one or more refractions. He remarked that two refractions by parallel surfaces of a prism will not serve, since the second surface destroys the effect of the first.

Descartes correctly analyzed the structure and function of the eye in the Third, Fifth, and Sixth Discourses of *Dioptrics,* and gave a quite modern account of the cues for distance vision, including lens contraction, convergence of the eyes, movement of the head, distinctness of form, distinctness of color, quantity of light, and the apparent size of the object. This material he used in Discourses Seven, Eight, and Nine to derive the theoretically correct surfaces for lenses, and the correct lens combinations for various purposes. He recognized and developed principles for spectacles, magnifying glasses, telescopes, and microscopes. In addition to providing the first theoretical, and theoretically correct, treatment of optics, Descartes proposed several useful devices, probably original with himself. These include the principle of the iris diaphragm, the drawtube, blacking of the inside of a telescope, and stage and substage equipment for the microscope, including a parabolic mirror for lighting by reflected light and a convex hyperbolic condenser for lighting by transmitted light. The theory of both telescope and microscope was well given, including questions of light-gathering power, useful aperture, magnifying power, focal length, brightness of image, spherical aberration, and so forth.

In dealing with heat, Descartes had less to say, but what he said was quite as important. He proposed the kinetic theory of heat two centuries before it was given serious consideration by the scientific world. This theory is given in the First Discourse, and elaborated in the Second Discourse of *Meteorology.* Along with this we find a premonition of Charles' law, since Descartes, in discussing water and water vapor, says that they occupy more space when the particles move more rapidly; and a suggestion of the conception of specific heat in that he argues that there is more

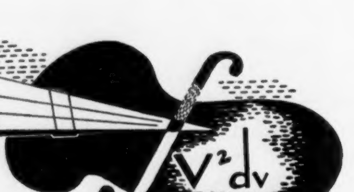
heat in concentrated masses, so that iron is hotter than the flame that heats it. These ideas were used to lay the foundations of modern meteorology. Descartes considered insolation to be the basic factor in weather production, and this insolation produces the evaporation of water from both sea and land. Difference of temperature produces winds which travel from a place where it is being heated to a place where it is being cooled. He recognized the nature of morning, evening, and sea breezes, and said that the complexities of the earth's surface make it almost impossible to predict the actual winds for each day, but that it is possible to predict what winds will be strongest and most frequent.

Fog, he said, is the same as cloud, both being formed by many small particles of water joining to produce drops of water or spicules of ice. The superficies of these disperse light; hence clouds are opaque. Any section of a drop parallel to the surface of the earth will be round. The size of the drop depends upon the quantity of moisture present and the degree of agitation of the air. When they are large enough, these drops fall as rain or dew: hail is formed when a raindrop freezes. Ice spicules are formed by cold acting on moisture in the clouds. An intermediate form between hail and rain is possible, consisting of snowflakes, which are interlaced ice spicules that appear white for the same reason that clouds do. The necessary conditions for the production of precipitation are a certain density of moisture on the one hand, and cold on the other. Neither alone is sufficient. It is always cold enough high up, and consequently the highest clouds are always composed of ice. Snowflakes fall as snow if the air is cold enough; otherwise they melt and fall as rain. The rain may be refrozen into hail, or sometimes an intermediate variety is formed, when the outside of the snowflake melts and refreezes, forming a particle of hail with a nucleus of snow. Since warmth is required for the production of hail, it is rare in winter. Moisture which freezes on touching the ground produces frost, particularly in the morning when the ground is cold.

We have seen that in addition to laying the foundations of modern meteorology, Descartes' contributions are basic in the theory of both light and heat. To this we must add his great importance in the field of mechanics, due to his invention of analytic geometry, the application of this to the analysis of motion by the use of vectors, and to the development, perhaps suggested by Descartes and certainly in consequence of his work, of the calculus. (Professor Kasner [Symposium on the "Life and Work of Rene Descartes," Columbia University, March 18, 1937] considers the calculus implicit in Descartes' geometry.)

I have been able here to touch only briefly upon the influence of Descartes' philosophical ideas on the development of modern science. There is also, reciprocally, the influence of scientific achievements upon general conceptions, and in this also Descartes has an important role.

From the earliest times when human thought was recorded, thinkers have hoped for a unifying principle to explain as many as possible of the diverse phenomena in experience, but up to the seventeenth century this "rational" attitude seemed confined to philosophers and theologians. The empiricist had a long record of discovering diversity, but no outstanding success in reconciling diversity into unity. It might well seem that the role of the empiricist was only negative and critical, like that of the Greek sophists or the modern Hume; playing, if you like, the part of God's loyal opposition. To achieve an important synthesis meant, then, for science, a very great encouragement and a much-needed spur to greater efforts. Contemporary histories credit this encouragement and spur to Newton's achievement of the synthesis of Kepler's and Galileo's laws into the universal law of gravitation. We should remember that Descartes doubly anticipated Newton: first in the fusion of algebra and geometry into analytic geometry, and second by the synthesis of heat and motion in the kinetic theory of heat.



Little Land

EMILY ERICSSON

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LIKE an eager setter pointing his discovery, Cape St. Vincent thrusts westward. Portugal lies on the western edge of the Iberian Peninsula, the westernmost tip of the Eastern Hemisphere, and from its location it has drawn its character. Since it lies between latitudes 36° and 42° N., it is the transition zone between the warm and the cold temperate. It is an Atlantic land, and, even though bounded on the north and east by Spain, dominated from time to time by Castille, it has not absorbed the Mediterranean character of its neighbor. To consider that the Iberian Peninsula means Spain-and-Portugal, a hyphenated name, and one geographic-political unit is a grave error. Portugal has always believed that economic and political evil have come to her from Spain, and the entire Portuguese-Spanish international situation may be summed up by the centuries-old proverb: "*De Espanha nem bom vento, nem bom casamento*" ("From Spain comes neither good wind nor good marriage").

The history of Portugal is ancient and distinguished. A unified people met the Roman legions and maintained a long and stubborn resistance. Even though the Romans were eventually victorious and held the land—called by them Lusitania—as an important part of the Roman Empire for more than five centuries, they did not change the essential Atlantic character of the inhabitants. The greatest Roman contribution was language, and today in certain regions in the northeastern mountains a language is spoken that derives directly from Latin, and not from corrupt Spanish, Gallego, or Portuguese.

Long before the twelfth century the region then called Portucalis was as well defined by geographic limits as it was by the marked characteristics of its inhabitants. In 1107 the first attempt at true unified rule was made when Henri de Bourgogne was named first Count of Portugal by his father-in-law, Alfonse of Castille. At that time the greatest part of present-day Portugal was in the hands of the Moors, who had first invaded the land in the eighth century and had driven the Lusitanians back into the interior. Now the Portuguese slowly descended from their mountains and again spread along the coast. Under Henri de Bourgogne, and later under his son Alfonso-Henrique, first King of Portugal, the Moors were repulsed repeatedly, and completely vanquished under Alfonso III. The house of Bourgogne gave nine kings to Portugal, among them Diniz, the Plowman King, who founded the University of Coimbra and laid down great plantations of pine along the Atlantic. A true mark of the Moors was deforestation, and the desolate character of much of southern Portugal could be remedied if today there were a Diniz to cover the eroded plains of the Alemtejo with trees.

The population of Portugal was originally of Iberian and Celtic stock, and types are still found with marked characteristics of the primitive inhabitants. In the north one sometimes sees almost pure Teutonic figures—descendants of the Visigoths, Vandals, Alans, and Suevi who overran Lusitania during the Roman occupation. The majority of the people today, however, show a very definite admixture of various bloods, particularly the Moorish. Although the Moors held Lusitania in military subjection and not as a unified nation, their imprint is unmistakable. Their influence still dominates in Portugal's art and architecture, lent much to its music, and affected its economy through their traditional love of treeless lands.

A curious phenomenon revealed by demographic study of Portugal is the stability of population distribution regardless of increase or decrease in total population. Today, Portugal has a population of 7,584,484; that is, almost seven million in her metropolitan area and nearly a million more in the Adjacent Islands. This is approximately twice the population of a century ago, when the census of 1838 listed 3,224,000 souls. Population distribution has remained the same throughout the country, however. There are two principal demographic regions. In area they are almost equal, but the north hinterland and the Alemtejo have less than one third of the population, whereas the north coastal and Algarve, excluding the populations of

Pine forest at Foja.

Lisbon and Oporto from the reckoning, have the other two thirds. Figures on the absolute population of Portugal for 1930 show that in the easternmost corner of Tras-os-Montes there were 28 inhabitants per square kilometer. Directly south of this, the figure rose somewhat and averaged 44 persons. The entire Alemtejo area dropped back to less than the figure for eastern Tras-os-Montes. In contrast, in the central part of Entre Douro e Minho,* there were 152 persons per square kilometer. This difference of concentration of population has always existed, and certain areas have remained almost stationary in their relative percentages. This quality, one might almost say aptitude, for permanency is evidenced in other phases of life in Portugal. It accounts for much of their political and economic history.

It is to be noted that wherever life is easier there is less concentration into agglomerations, but a greater over-all density of population. South of the Douro River, and in Algarve, the system of small and medium holdings is favored. Tenant farming and sharecropping exist, but they are not the rule, as dispersion of the habitat has been in progress in these regions since the Middle Ages. The houses have gradually spread out into clearings in the pinelands, even out onto the sandy coastal plain. In the Entre Douro e Minho region dispersion began even as early as Roman times, although the more usual organization then was concentration on the heights to provide mutual protection. The houses of Douro e Minho are influenced by this dispersion and by the individual working of the land, as well as by the climate. They are low, grey, solid. The bright tiles and colors of the southern regions are not repeated here except in the attempts at more modern architecture. The communes in Entre Douro e Minho, many of which go back to Roman times, are made up of hamlets, groups of a few houses, and isolated dwellings. Large villages are not the rule.

Oporto, chief city of the north, second city of all Portugal both by population and by commerce, is the oldest city in the country. Legend recounts that it was founded by a Greek, son-in-law of Pharaoh. Others believe the Carthaginians were the founders; still others claim the Suevi. First called Portus Cales, later Portucalia, it has given its name to the entire country. Twenty times destroyed by Goth and Moor, twenty times Oporto rose. Of all the cities in the world, the name of Oporto has, perhaps, the most renown. Although St. John is the patron claimed by the Portuenses, the true patron saint of Oporto is Bacchus, for it is the wine of Oporto that has made both its name and its fortune. The gathering of the grapes—the preparation of the wine—is not only a science, it is almost a cult.

South of the Douro, in the Ria de Aveiro region, the houses do not cluster together but follow the roads, so that villages tend to be merely long streets bordered with houses. This straggling character was possible in coastal lands much earlier than in the interior, for more was to be feared from invasion by land than by sea. In addition, the excellent possibilities for earning a living affected the character of the dwelling. In the Ria de Aveiro region, as well as to the north in Entre Douro e Minho, individual effort sufficed to provide food and shelter. The land was fertile, the climate moderate, the rivers and the ocean furnished food. The Aveiro lagoon, separated from the sea by a range of dunes, was an early center of maritime life. Today, the painted boats, prow and poop upswept like a gondola, are still poled through the canals, loaded with algae, with salt, and with fish. Animals graze on distant salt marshes, and one has the impression that they walk upon the limpid water of the lagoon.

Contrary to the enchantment of this land near Aveiro, the interior of Portugal is inhospitable. North of the Tagus the land rises in a high plateau, whose prevailing winds are cold, dry, and unproductive, robbed of all moisture by the high Spanish desert lands over which they have passed. In popular speech this plateau is called *Terra Fria* because of its rigorous climate. Here, in addition to the need for agglomerations because of climate,

* Former name for coastal region above the Douro River, now partially included in the province of Minho.

there was also the need for mutual protection. The *Terra Fria* lies next to Spain, and the Tagus Valley has long served as one of the main routes to connect the two lands, although the Tagus itself is not navigable for its entire length. The formation of groups was natural, and here the system of agglomerations dominates. Communes are often a single large village and much of the work is done by communal enterprise. In this area the excess population has long been carried off by emigration, and the old types of dwellings have been preserved.

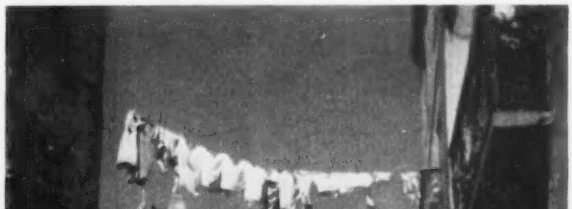
Directly north of the Tagus, before the plateau begins, lies one of the most important sections of all Portugal. This region is largely included in the modern provinces of Ribatejo and Estremadura. The land is rich sediment, and there is sufficient moisture to produce wheat, corn, beans, and grapes. Large olive groves, cork orchards, and eucalyptus forests abound. In spite of the extreme diversity of it relief, this is one of the most cultivated provinces, since of its 1,833,680 hectares there are 1,064,597 under cultivation. This region of Ribatejo and Estremadura, formerly all known as Estremadura, is one of the most important of all Portugal. The greatest national problems have been decided here by arms. Lisbon, lying in the estuary of the Tagus, has had geographic reasons behind her political dominance—a dominance so great and so old that, according to dictum, "Porto works, Coimbra prays, Lisbon governs."

Ancient legend tells us that a crusading knight, led by his faith to Jerusalem, asked a magician to show him the most beautiful city of Europe. Before his eyes arose the vision of Lisbon. Many another voyager has shared his astonished pleasure. Lisbon is truly a lovely city, sweeping from the Tagus to the hills beyond, but Lisbon is not European, and the traveler who knows Europe and America well receives a totally new impression when first he sees Lisbon. It is a dazzling white, and no tower or overwhelming building breaks the suave and sinuous line of its rooftops.

Little remains of the Lisbon built before the earthquake of 1755. Fire and tidal wave destroyed its little *manuelin* chapels, its sumptuous royal palace, thousands of its inhabitants. Only here and there stands a house which withstood the holocaust. Such a one is to be found next to the Museum das Janelas Verdes, and in its garden are the rings where once the boats of the Tagus tied up, for the river did not then run where we find it today. Modern Lisbon is the work of one man, the Marquis de Pombal, who was the true ruler of Portugal during the reign of the gentle King Jose I. The heart of Lisbon is the lower city, the city of Pombal. Here are the banks, the gold- and silversmiths, the law courts, and the ministries. The section is known simply as the Baixa, and its streets record the industries that have flourished there: Rua da Prata, Rua do Ouro, Rua dos Sapateiros, Largo do Trigo ("Silver Street," "Gold Street," "Cobblers' Street," and "Wheat Square").

Although the center of Lisbon was destroyed in 1755, outlying districts were only partially damaged, so that on the west the magnificent monastery of the Jeronimos was preserved and on the east the miserable quarter known as the Alfama also escaped destruction. This quarter was formerly the heart of Lisbon. Later, it became the place of refuge for Jew and Moor who, ordered by King Manuel to quit the country, sought shelter here until some more hospitable country could be found. Today it still stands, a maze of narrow streets that twist and climb and lose themselves in archways, a perfect sample of a medieval town. The debris of the city walls built in the time of the Visigoths forms part of the walls of the old houses.

Lisbon is a city of contrasts. Side by side with the barefoot venders of sardines and live chickens go women dressed by the *grands couturiers* of France.



Alfama in Lisbon.

In the courtyard of an ultramodern apartment house in the upper city will be a chicken coop and rabbit hutch, and a few cabbage plants to supply the green for the daily *caldo verde* of the working people. In 1946, on a flat space of roof directly over the kitchens and outside a guest's window, one of the big hotels kept a goat.

South of the Tagus, directly opposite the fertile lands of Ribatejo and Estremadura provinces, begins the vast Alemtejo plain, domain of tenant-farming, sharecropping, and hereditary leases. Once this plain rivaled Sicily as a granary for Rome, but today it lies uncultivated except for minor efforts. Goats, hogs, and some cattle graze over it. The lands near Beja, Evora, and Elvas still produce fine fruits and vegetables, and the melons of Alemtejo would do well in any market. Their small-sized sweet watermelon would have an excellent market abroad, as would also the several varieties of cassava, cantaloupe, and Persian. Unfortunately, this melon industry is not developed. Watermelon is considered food for peasants and is never served in any hotel or restaurant. It is not even served in a private home except after long battles with the cook. Neither is full advantage taken of the other types of melons—they are all simply *melão*, and it is impossible to order a specific type or variety. The headwaiter of the Palacio Hotel in Estoril, a French waiter employed there, and an editor of documents in the Ministry of Agriculture all insisted that the varieties are merely *melão*; sometimes one has one, sometimes another, "*não faça mal*" ("that's no harm"). Only the Frenchman appeared disturbed by the lack of accuracy.

The Alemtejo is very dry and is sparsely settled. The vast, isolated farms, usually called *monts* because they are customarily situated on high ground so that they look out over the country, have long been in the hands of great families who have neglected their cultivation. This neglect has been traditional. The Alemtejo was well irrigated and cultivated under Arab rule, but the Crusaders destroyed the olive groves and the irrigation systems as they reclaimed the land from the infidel and fought among themselves over the conquered territory. Following this reconquest, large gifts of land were made to the lords, to military orders, and to convents. In the fifteenth century King Diniz attempted to persuade the nobility to return to the land, but they neglected the exploitation of these *latifundia* to such a point that special laws finally confiscated the fallow lands; a great deal of land was put back into cultivation, and villages grew up. These have long since disappeared, for the great sea discoveries again spelled disaster for the Alemtejo. They eventually drew away her workers, and farming was abandoned except near the cities. The Alemtejo became the domain of shepherds, swineherds, and charcoal burners. Other efforts have been made at various times to break up the remaining large properties, and to spread the inhabitants into scattered houses, but dispersion is not common and the sharecropping continues. In times of drought, the misery in the Alemtejo beggars description. Men, women, children, even from time to time an old donkey, plod the dusty, flat roads. The poor of Lisbon are poor indeed, but frequently because they wish to be. The poor of the Alemtejo have no other choice.

Market day in Alemtejo.

Although the center of agricultural life is the farm, the city is needed for exchange, and in this formerly rich and abundant area four large agglomerations have been known since early days: Portalegre, Elvas, Beja, and Evora. Evora, the old *Liberalitas Julia* of Caesar's day, now capital of the Alemtejo, is built among gardens and orchards on top of a hill which dominates the desolate plateau. At dawn, in the clear light of this southern land, the country people, dressed in skins, can be seen from afar, plodding toward the market place. The charm of modern Evora is in the fragments of her

past: a fine Roman aqueduct, Corinthian columns from a temple of Diana, feudal debris from the days when Sancho I (1154–1211) made Evora his court. The city of the Moors is gone. No tangible evidence remains of their domination, but curiously enough the intangible they left as heritage has more influence and is better known to the world than any of the other legacies, for they left artistic traditions and gave the town its name, Yeborath.

As much as the Alemtejo plain is desolate and sad, the region of Algarve is productive and smiling. Algarve is a charming province of flat-roofed Moorish houses, salt flats, and hills overlooking the sea. It is the only one of the political divisions of Portugal that has kept its original boundaries as kingdom, region, district, and province. The original Moorish kingdom had included lands in Africa as well as in the Iberian Peninsula, so that the title taken by the Kings of Portugal was Rei do Portugal e dos Algarves, with fine disregard for the Moorish definite article.

Algarve is a land of alluvial soil greatly enriched by fertilizers from the sea. Its hills and terraces are completely cultivated, so that on every side are gardens, orchards, and fields. The tourist time in Algarve is February, when the white blossoms of the almond trees bring to this southern coast the only snow it ever knows. However, in other seasons, orange and fig, olive and carob, lend grace as well as value. Wheat, barley, rye, and all the vegetables of a southern climate mature well and early. Added to this agricultural value of the land is the value of the sea, which produces along this coast the greatest of sardine and tuna fishing. The self-sufficiency of Algarve has been one factor that allowed her to stay ever within the same boundaries; to maintain her curious Moorish chimney pots and Arabic words; to keep her women black-kerchiefed and—in certain regions—veiled, until very recently.

Even as the Portuguese has clung to his customs, his traditional type of village, and to the region in which he was born, so has he clung to his history. If Portugal ever takes a place of authority in the modern world, it must come through the have-nots. The ordinary young Portuguese today is made inert by consideration of the glories of his ancestors. Only those who do not know their ancestors have the courage to make their own twentieth-century lives. Too often not even they dare the competition, and they hark back to Vasco da Gama and Henry the Navigator to establish their importance.

Antonio Oliveira Salazar is an example of the young Portuguese who look toward formation of a modern state worthy of the distinguished history that is their heritage, but who do not rely upon that history for present glory. He is an interesting figure and the only modern dictator with education. The son of a relatively poor and certainly obscure family, he distinguished himself in his law studies at Coimbra. His personal life is without scandal. About him there is none of the swashbuckling of Franco and Mussolini, none of the fanatical demagoguery of Hitler. He is cool, intelligent, educated, intensely patriotic, and, whatever may be his faults, he has the virtue of sincerity.

Portugal today is a corporative state defined by its constitution of 1933 as "a unitary and corporative Republic, based on the equality of citizens before the law, on the free access of all classes to the benefits of civilization, and on the participation of all the constituent elements of the nation in the administration and making of its laws." The thought that engendered the new organic structure of the nation was directed to two ends, and was a summation of the aspirations of the National Revolution. The first of these ends proposes to restore to the family and to the laboring occupations the functions that naturally belong to them. The second proposes to reconstruct the traditional and historic institutions of local or regional administration that constitute the framework of the state.

Theoretically, in the corporative association system, workers of a given occupation draw together into a mutually beneficial guild so that all economic interests converge on a social plane and are integrated in the superior interest of the nation. Actually, auto-organization has been so slow that the state has felt obliged to interfere, and, although Portuguese corporativism is in principle by association, in reality it is mixed. That is, it is vertical as well as horizontal and proceeds as much by delegation of authority as it does by true convergence. The chief of the government is the President, elected for a period of seven years. General Oscar Fragosa Carmona has held this office since 1933.

Portugal was formerly divided into "districts" based on the model of the French department. Under the Administrative Code of December 3, 1936, these districts were replaced by provinces, made up of communes. The stated purpose of this redivision was to adapt new conditions of national life to the political setup and to the administrative divisions. A province is defined as "an association of communes, presenting geographic, economic, and social affinities." The communes are further divided into parishes, and each parish has its meeting. There is a council for each commune and a provincial assembly for each province. Impetus is given the communal councils and the provincial assemblies by the parish meetings where, theoret-

ically, the humblest village needs are made known. The new provinces have been so designed that old districts are cut up and redistributed. Furthermore, there is no national territorial representation of the people, for the legislative branch of the government is a National Assembly of ninety members elected from the professional classes every four years by the vote of all heads of families, whether men or women. A corporative chamber of ninety representatives, elected by the occupational corporations, acts in a consultative capacity. This Corporative Chamber has been called the peak, the synthesis, and the master pattern. It supposedly constitutes a bond betwen the trade and agricultural world and the professional world. In actual practice this means that a unicameral system exists, for the Corporative Chamber has no power whatever; it may only suggest.

The National Assembly has very little more authority than does the Corporative Chamber. This is chiefly due to the question of ministerial responsibility. The Prime Minister is appointed by the President and is responsible to him only, and not to the Assembly. The Prime Minister, in turn, appoints and dismisses his cabinet at will. The voice of the people, therefore, is very effectively stifled, not only by the restricted franchise, but by the system of ministerial responsibility.

Salazar has been Prime Minister since 1932. From 1926 until 1932 he held the post of Minister of Finance, but gradually took upon himself the duties of various ministries until by 1942 he held the portfolios of War, Finance, and Foreign Affairs, as well as that of Prime Minister. After the second world war he released some of his titles to figurehead appointees.

Although the two most vocal exponents of fascism in the Western world, Italy and Germany, have been silenced, the seed and germ for a new fascism remain in the Iberian Peninsula. Its retention or modification in Portugal and Spain will largely determine the future political scene of the world. As compared to Spain, relatively little attention has been given to Portuguese dictator theories, although the Portuguese new state is the purest form of the authoritarian state. The chief factor in bringing the bulk of popular attention to Spanish activities is that Spain became a purely totalitarian government only in 1939, and as the outcome of four years of bloody warfare. The public eye was upon her, and she emerged into a world where such form of government was already known. By that time political theorists could recognize the structure of a dictatorship when it appeared.

Portugal, on the other hand, became an authoritarian state as early as 1926. The government was modeled upon the Italian plan and was the second of its type. In those days no very clear conception of corporativism existed, and inasmuch as few people in the democracies understood such government, even when proclaimed in a nation as great as Italy, it is comprehensible that a small country, long unimportant and revolutionary, drew no attention when an obscure university professor promised to balance the budget, provided he be given complete power. In the first months of his career he almost lost that power, but by his return to the University at Coimbra, and by his refusal to work with the government except on his own terms, he forced Parliament to accede to his demands. Thus he settled for all time the question of personal-dictator authority as against popular will in the new state.

It should be noted, however, that the personal dictator in Portugal is not the infringement on individual right that a similar institution would be in the United States. Historically, Portugal presents a fertile field for the development of a modern dictatorship. Under one faction or another of the royal house, under the Republic of 1910, or under Salazar, Portugal has had great colonial wealth concentrated in the hands of a few; ignorance, disease, and poverty among the remainder.

Portugal is a seafaring nation with a long record of colonization and exploration. Under Prince Henry the Navigator, mathematicians and navigators worked out plans for exploration of the "Sea of Darkness" beyond Ceuta and for the establishment of the vast empire beyond the seas. Even today, Portugal holds the fourth largest colonial empire in the world. It was this colonizing power which in the fourteenth century attracted her weak neighbor, England, and bound them together until the role of protector and protected became reversed and the British Empire today finds in a peaceful, weak Atlantic country with a great colonial system one of the best supports to her own colonial policy. In this sisterhood is to be found an explanation for the support formerly given to Portuguese bad government by Great Britain. Fugitive kings are made welcome. Too much turmoil in Portugal would result in colonial improvements, if not in actual losses of territory. The precedent would be disadvantageous to all holders of colonial empires. Colonial wealth has always played a big role, and under the constitutional monarchy was so dominant that the parliament was a weak organism, representative of foreign interests and of colonial wealth, rather than of the people. At no time have the people been able to achieve for themselves a real voice in their gov-

ernment, even though there was formerly a semblance of political parties and free elections.

At present all political parties except the National Union have been abolished. In reality, the National Union, which is the Portuguese counterpart of the old National Socialist Party in Germany, cannot be considered a political party in the democratic sense of the word, for it is merely the voice of the state. Salazar has no belief in government by parties and politicians and considers that the chief error of the nineteenth century is the idea that English parliamentarianism and democracy must be adaptable to all European countries. Elections in Portugal have been described by Salazar as "in the nature of a plebiscite. The votes polled will not be in favor of any particular candidates, but will signify the recognition of the benefits of our system and the country's adherence to the fruitful principles of the National Revolution."

The most important single political *group* is the Legião Portuguesa. It embodies the principles upon which the government is built. From a military point of view, the Legion is an active reserve of the Army and Navy. During the Spanish Civil War the Portuguese Legion fought in Spain to help Franco, and during the second world war Legionnaires fought with the Spanish Blue Division to aid the Germans on the Eastern Front. Portuguese Legion "observers" were guests of the German General Staff on all fronts. From the point of internal administration of the country, the Legion acts to keep Salazar informed as to political activity; in this it is aided by the P.V.D.E. (Policia da Vigilancia e Defesa do Estado), the so-called International Police of Portugal.

The Legion is reputed to have a social service side too, and to furnish medical and unemployment aid to its members. It does, indeed, maintain both boys' and girls' groups. One of the finest buildings in Lisbon is the headquarters of the Portuguese Youth Movement, the Mociedade Portuguesa. Hours of watching the young men at their drill and play revealed no discourtesies, no fights. They apparently enjoy their games and run to them with pleasure after the day's drill, but their play activities give the watcher a sense of unreality, as though a well-rehearsed May fete were being enacted. This acceptance of form without substance is one of the most noticeable features of all Portuguese life.

The Portuguese inability to see conditions in their true light results largely from a lack of experience. The people are kindly, intelligent, and interested in their fellow-men, but they are colossally ignorant. They have no means of comparison. They resemble the child who believes his back yard to be the

Young shepherd of Estremadura.

biggest place in all the world, merely because he has not even seen the city park. This lack of comparative sense, this inability to separate reality from desire, is the chief obstacle in the way of any popular social or political movement.

Because of this quixotic belief in an ideal, this confusion of hope and reality, foreign observers have often said that the Portuguese are stupid. They definitely are not. They are untutored. It is a question of "other days, other ways," for the mass of the Portuguese today live as their great-grandfathers lived. They lack the education necessary for any other life. Even the wealthy and the educated, with radios, Harvard degrees, and Bond Street clothes, live many decades behind the present. They cannot escape such an existence, for the most illiterate member of a nation determines the literacy of that nation and the degree of culture to which it can aspire. In 1940 illiteracy in Portugal amounted to approximately 74 per cent. Since that time some progress has been made, and today it is claimed that the figure does not exceed 55 per cent of the population. This figure, is however, attained by estimate and not by census. It is further held that the illiterates are now found only among the older people and that the young are all literate. The question then arises as to what may be termed "literacy." If an individual can form a few letters, tell the time, read the name of a town on a railway station, he is literate, but he is still far from literate in the sense that he can read newspapers or books, even of the most popular type. The people of Lisbon and Oporto are the most advanced. Maids, waiters, and other help in foreign

diplomatic households in those cities are the best of their class, and yet one who can spell even the most elementary words of his profession is rare. During the war the use of ration cards was impossible as the people were, in general, unable to read them. This situation is true not only among the servant group, but also in the middle and upper classes. It is not uncommon to have a well-dressed lady of distinguished deportment ask for help with the printed word—if by chance circumstance has forced her out to attend to some detail of passport or postal formality. Usually, such women do nothing of the kind for themselves.

This lack of education has tremendous influence on press, radio, and theatre. Newspapers have little space for learned editorials or letters to the editor. An occasional column addressed to women readers is of an almost insulting vagueness and inaccuracy. Advertisements limit themselves to superlative forms of the adjective.

Commerce is adversely affected by the inability of the people to read and by their lack of training in investigation. There is no healthy skepticism, but there is fanatical adherence to an idea engendered by some emotional appeal. They are not taught to question or to compare. As one maid put it, she knew that she had bought the brand of DDT ordered because it was in a yellow can exactly the same color as the one that the *senhora* had brought from America. Such people are the easy prey of the unscrupulous merchant, and all the laws enacted cannot protect them. Portuguese law is some of the most beautiful ever written. It is a pleasure to read, to translate, and to contemplate. It is not a pleasure to watch in its functioning. Every law may be interpreted to fit any occasion, and one shudders at the interpretations that might arise were a ruthless government to replace the present one. This broad scope of Portuguese law has been a source of constant surprise to other governments, who have many times failed to appreciate the real quality of apparently quite innocuous legislation.

Nothing can protect ignorance, and until admiration of learning shall replace the pretense traditionally affected by wealthy Portuguese, little real progress will be made. As late as the beginning of the nineteenth century the fidalgos, or hereditary lords, held not being able to read as a point of honor

Girl with oxen, Foja, Portugal.

and confined their ambition to three activities: horseback riding, the conquest of women, and bull-fighting. Their descendants continue to consider work disgraceful, and they cannot understand why work is ever undertaken except in case of financial need. Unfortunately, this attitude has spread out into the fringe of the wealthy, so that a vast number of the common people have been made inert by this philosophy. In fact, today these would-be gentlemen are the guardians of the belief, for the wealthy Portuguese have begun to realize that they must return to the precepts of King Diniz, planter of pine forests, musician, and poet, who recognized that work is the most noble attribute of all nobility and who drove out of Oporto all those nobles scornful of commerce as being incompatible with their position.

The soul of a country is made truly articulate only by its common people, and the soul of Portugal is revealed as delicate, naïve, and sad. Although the people are unschooled and illiterate, they are not without knowledge and culture. They have a delicate appreciation and sense of imagery, and through no medium is this so well expressed as through their language. The common names for flowers are rarely equaled in other tongues: "princess ear-drops," they call the fuchsia; "perfect loves," the pansy. Their poetry, whether of North or South, expresses the same soul; the same pride—that of great discovery; the same regret—that of loss: eternal regret and the fatalism so well expressed in the word *saudades*,* sung in the *fado*. The *fado* (the word means "destiny") is known to more foreigners than other forms of popular song and verse because it belongs to Lisbon and to the South. Born of ancient Moorish poetry, the *fado* is perhaps the last serenade; *fado*-singers the last troubadours. Whether to honor a saint on his feast day or to recount a tragic love, the *fado* never changes. It is ever a tragic cry rising from the soul of the people.

Another very special form of poetry in Portuguese literature is the quatrain. Although this form has been created by the language itself, with a rhythm dependent upon the stress accorded the word, the freshness and naïveté of the thought are not lost in translation.

* Translated both as greeting and farewell, the meaning is essentially "nostalgia."

Countryside near Foja.

1

Thou the shadow, I the sun
Which shall we say more dear?
In summertime the shadow cools
In wintertime the sun brings cheer.

2

I do not ask to be your life
But, rather, soul am I.
For life must always end in death,
The soul can never die.

The most dominant force among the people is religion. Intensely superstitious, almost pagan in many ways, they have so integrated Christian observances with ancient celebrations of harvest and seafaring that they do not distinguish one from the other.

The Portuguese people are often called insensitive. Foreigners are horrified by the tiny, scrofulous babies frequently exploited by beggar children no more than four or five years old. True enough, the Portuguese does not have a highly developed sense of social responsibility beyond that which affects his own family, but he is not insensitive or unkind. He is discouraged. His is a tragic history. Fatalism dominates his entire life. He has learned that man was made to suffer and, with all the plodding patience of his own little grey donkey, he accepts his lot.

The Basic Concepts of Calculus

F. D. MURNAGHAN

The author, who is head of the Department of Mathematics at the Centro Técnico de Aeronáutica, Rio de Janeiro, discussed in the April 1949 issue of THE SCIENTIFIC MONTHLY *"The Evolution of the Concept of Number." In the article below he presents the basic principles of the differential and integral calculus from a point of view that may be new to many readers.*

The Concept of Differentiability

EVERY student of differential calculus learns that a function $y = y(x)$ of a single real variable x is differentiable at a given value x of the independent variable if, and only if, the ratio $\frac{\Delta y}{\Delta x}$ possesses a limit as Δx tends to zero and that this limit (when it exists) is the derivative y_x of y with respect to x (at the given value of x):

$$y_x = \lim_{\Delta x \to 0} \frac{\Delta y}{\Delta x}$$

Thus, in order to understand the fundamental concept of differential calculus (the derivative of a differentiable function), we must understand clearly (a vague idea is not sufficient) what is meant by the limit of a function of a single independent variable at a given value of the independent variable. Unfortunately for the beginning student, this concept is sophisticated and difficult to master, the essential reason for this difficulty being that the very concept of a real number is sophisticated and difficult. Every student of differential calculus learns that a function $y = y(x)$ of a single real variable x possesses a limit l at a given value a of x if the difference $\{y(x) - l\}$ may be made arbitrarily small by making the difference $\{x - a\}$ sufficiently small:

$$|y(x) - l| < \epsilon \quad \text{if} \quad 0 < |x - a| \leq \delta$$

Here the vertical lines denote, as usual, the absolute or numerical or unsigned value of the symbol which they enclose. A well-taught student learns to distinguish between the two positive numbers ϵ and δ; ϵ is "arbitrarily small" (which is merely a circumlocution, sanctioned by usage, for the briefer and understandable word "arbitrary;" the circumlocution "arbitrarily large" could be used just as well as "arbitrarily small," both meaning nothing more than arbitrary), whereas δ is "sufficiently small." ϵ must be known or assigned before we can decide what value to assign to δ so that the inequality $|y(x) - l| < \epsilon$ may be valid. Just because this is an inequality and not an equality we cannot say that δ is a function of ϵ; for once ϵ has been assigned and a value of δ determined, any positive number $\delta' < \delta$ will serve just as well as δ. If, however, we understand by δ a number which is such that $|y(x) - l| < \epsilon$ if $0 < |x - a| < \delta$ while no greater positive number δ' possesses the property that $|y(x) - l| < \epsilon$ if $0 < |x - a| < \delta'$, we can say that $\delta = \delta(\epsilon)$ is a function of ϵ (it being understood that δ is undefined if the inequality $|y(x) - l| < \epsilon$ is valid, for a given value of ϵ), for every x for which $|x - a| > 0$.

Let us now examine carefully this limit concept. In the first place, the inequality $0 < |x - a|$ is an *essential* part of the concept. The value a of x is not allowed to enter the discussion. It is clear, then, that, if $y = y(x)$ is defined at $x = a$, the particular value which y possesses at $x = a$ does not affect the existence or nonexistence of a limit of $y(x)$ at $x = a$ and, if this limit exists, its value does not depend on the value $y(a)$ of $y(x)$ at $x = a$; $y(x)$ does not even have to be defined at $x = a$ for $y(x)$ to possess a limit at $x = a$. This is the first point which must be thoroughly understood:

The existence or nonexistence of a limit for $y = y(x)$ at $x = a$ does not depend on the definition or nondefinition of $y(a)$. If $y(a)$ exists, the value of the limit l of $y(x)$ at a, if this limit exists, does not depend on the value of y at a.

Note: A thorough comprehension of this fact is essential in the case of the definition of the derivative y_x of y at the point x. The variable whose limit, when it exists, is y_x, is $\frac{\Delta y}{\Delta x}$, and this ratio is not defined at $\Delta x = 0$. You must really believe this; do not have the feeling that if you know the values of $\frac{\Delta y}{\Delta x}$

for "sufficiently small" values of x (naturally different from zero [why?]) you can by some process of intuition know "the value" of $\frac{\Delta y}{\Delta x}$ at $\Delta x = 0$ and then say that this "value" defines y_x at x. The value of a function of a given independent variable at any given value of this independent variable is quite independent of the value of this function at any other value (or all other values) of the independent variable. You may, of course, *after* you have investigated the question of the existence or nonexistence of a limit of $\frac{\Delta y}{\Delta x}$ at $\Delta x = 0$ and found that this limit exists and has the value l, extend the field of definition of the quotient $\frac{\Delta y}{\Delta x}$ by defining a *new function* which has the value l if $\Delta x = 0$ and the value of $\frac{\Delta y}{\Delta x}$ if $\Delta x \neq 0$. Then y_x is, of course, the value of this new function at $\Delta x = 0$; but, if you do this, be careful not to fall into the error of thinking that this serves as a definition of y_x at x. You must first know the value of y_x at x before you can define the value of this new function (which you may, if you thoroughly understand what is going on, denote by the symbol $\left.\frac{\Delta y}{\Delta x}\right)$ at $\Delta x = 0$. *Query*: What is the independent variable which occurs in the definition of y_x as a limit? *Answer*: Δx; not x. The quotient $\frac{\Delta y}{\Delta x}$ is a function of *two* independent variables, x and Δx; but, in the examination of the question concerning the existence or nonexistence of a limit at $\Delta x = 0$ of the quotient $\frac{\Delta y}{\Delta x}$, x is held fixed so that $\frac{\Delta y}{\Delta x}$ becomes a function of only one independent variable, which is, however, not x but Δx.

Having seen that the question concerning the existence or nonexistence of a limit of a function $y = y(x)$ at $x = a$, and of the value of this limit if it exists, is not affected by the definition, or lack of definition, of $y(x)$ at $x = a$ or by the value of $y(a)$, if $y(x)$ is defined at $x = a$, the question remains: on what does the question of the existence or nonexistence of a limit of $y(x)$ at $x = a$, and the value of this limit if it is defined, depend? It is clear that it does *not* depend on the definition, or lack of definition, of $y(x)$ at any single point b different from a; for, once b is given, we can always choose $\delta < |b - a|$. Thus, no matter how many values of x you mention or what these values are, I have to reply: They have no interest for me since the question as to whether $y(x)$ has a limit at $x = a$ or not, and the value of this limit if it exists, do not depend on the definition or lack of definition of $y(x)$ at these values of x nor on the values of $y(x)$ at these values of x (if $y(x)$ happens to be defined at them). On what, then, do the questions of the existence or nonexistence of a limit of $y(x)$ at $x = a$, and the value of this limit if it exists, depend? The only possible answer is the following rather vague one: On the values of $y(x)$ at the points of an arbitrarily small neighborhood of a, it being understood that this neighborhood is *punctured* by the removal from it of the point a itself.

In order to simplify as much as possible this sophisticated concept of limit we observe that the concept of a function $y = y(x)$ having a limit l at a value $x = a$ of the independent variable may be based on the concept of a function $z = z(x)$ having the limit zero at $x = a$. All we have to do is to introduce the function $z(x) = y(x) - l$; it is, then, clear from the very definition of a limit (show this) that $y(x)$ has the limit l at $x = a$ when, and only when, $z(x)$ has the limit zero at $x = a$. What, exactly, do we mean when we say that $z(x)$ has the limit zero at $x = a$? Neither more nor less than the statement that $|z(x)|$ may be made arbitrarily small by making the *positive* variable $|x - a|$ sufficiently small

$$|z \leq (x)| < \epsilon \text{ if } 0 < |x - a| \leq \delta.$$

It is convenient to have a short name for a function, or dependent variable, which has the limit zero at $x = a$; we shall say that the function is *null* at $x = a$. What advantage has the concept of a function being null at $x = a$ (on which the concept of a function having the limit l at $x = a$ can be so easily based) over this latter concept? Simply this: We do not leave the class of functions which are null at $x = a$ by forming linear combinations of members of this class. In other words, it is evident from the definition (show this) that:

1) if $z = z(x)$ is null at $x = a$ and c is *any* constant, then cz is null at $x = a$,

and,

2) if $z_1 = z_1(x)$ and $z_2 = z_2(x)$ are both null at $x = a$, then $z_1 + z_2$ is null at $x = a$.

This advantage is not possessed by the class of functions $y = y(x)$ which have a given number $l \neq 0$ as limit at $x = a$; if $y = y(x)$ has the limit $l \neq 0$ at $x = a$, then cy has a limit at $x = a$, but this limit is not, if $c \neq 1$, l but cl, and if two functions $y_1 = y(x)$ and $y = y_2(x)$ have the limit $l \neq 0$ at $x = a$, their sum $y_1 + y_2$ has a limit at $x = a$, but this limit is not l but $2l$.

There is an immediate generalization of the property 1) of null functions which is very useful, but, in order to state this generalization in a simple manner, we must first define the concept of a *bounded function.* This is very simple (and, therefore, very important): A function $f(x)$ is bounded if, and only if, there exists a constant c (necessarily nonnegative) having the property that $|f(x)| \leq c$ for all values of x for which $f(x)$ is defined. If $f(x)$ is bounded when x is restricted to lie in a sufficiently small neighborhood of a value a of x, we say that $f(x)$ is *bounded* at a. Thus $f(x)$ is bounded at a if there exist a constant c and a number δ such that $|f(x)| \leq c$ if $0 < |x-a| \leq \delta$. Note carefully that, just as in the case of the limit concept, a function may be bounded at a without being defined at a. Then null functions possess the following useful property:

3) if $z = z(x)$ is null at $x = a$ and if $v = v(x)$ is bounded at $x = a$, then the product $v(x)z(x)$ is null at $x = a$.

The proof of this is an immediate consequence of the property 1) of null functions and of the following:

4) if $z = z(x)$ is null at $x = a$ and if the function $f(x)$ is such that $|f(x)| \leq |z(x)|$ over a sufficiently small punctured neighborhood of a, i.e., if

$$|f(x)| \leq |z(x)| \text{ if } 0 < |x-a| \leq \delta,$$

then $f(x)$ is null at $x = a$.

(Prove this.) It follows (show this) that, if two functions, $z_1 = z_1(x)$ and $z_2 = z_2(x)$, are null at $x = a$, so also is their product. Thus the sum and product of any two null functions are null functions. Expressed somewhat technically, the class of functions which are null at a value $x = a$ of the independent variable is closed under addition and multiplication.

It follows (show this) that any polynomial function of one or more null functions, with coefficients which are either constant or merely bounded at the value a of x at which the function (or functions) are null, is null at $x = a$.

After these preliminaries we may rephrase the definition of differentiability of a function $y = y(x)$ as follows: The function $y = y(x)$ is differentiable at a value x of the independent variable if there exists a function y_x of x which is such that the function $\frac{\Delta y}{\Delta x} - y_x$ of Δx is null at $\Delta x = 0$.

Using the symbol ν to denote a function of Δx which is null at $\Delta x = 0$, the definition of differentiability of the function $y = y(x)$ may be written, without words, in the form

$$\frac{\Delta y}{\Delta x} - y_x = \nu$$

or, equivalently,

$$\frac{\Delta y}{\Delta x} = y_x + \nu.$$

This formulation still has the disadvantage that the teacher must continue to insist, against the beginning student's better judgment, that we must be careful not to evaluate $\frac{\Delta y}{\Delta x}$ at $\Delta x = 0$ (why?). However, we can write the relation $\frac{\Delta y}{\Delta x} = y_x + \nu$ in the form $\Delta y = (y_x + \nu)\Delta x$; these two relations are equivalent when $\Delta x \neq 0$, but the second is valid when $\Delta x = 0$ (for Δy is zero when $\Delta x = 0$). When $\Delta x = 0$ we *agree* that $\nu = 0$ (the relation $\Delta y = (y_x + \nu)\Delta x$ would be valid when $\Delta x = 0$, no matter what value we assign to ν). Thus the definition of the derivative of $y = y(x)$ at a given value of the independent variable may be written as follows:

If Δy may be written in the form $\Delta y = (y_x + \nu)$ Δx where y_x is independent of Δx and ν is a null function of Δx at $\Delta x = 0$, then we say that $y = y(x)$ is differentiable at x and we term y_x the derivative of y.

Note: The fact that y_x is unambiguously determinate is clear; indeed, the equation $y_x' + \nu' = y_x + \nu$ assures us that $y_x' - y_x$ is null at $\Delta x = 0$. Being independent of Δx it must be zero (why?). Hence $y_x' = y_x$.

What advantage does this formulation have over the usual form of the definition of the derivative? Well, it follows at once that the property of differentiability is closed under addition and multiplication. Thus the fundamentally important theorem which runs as follows:

If $y_1 = y_1(x)$ and $y_2 = y_2(x)$ are differentiable at x, then the sum function $s(x) = y_1(x) + y_2(x)$ is differentiable at x, and its derivative s_x is the sum of the derivatives of $y_1(x)$ and $y_2(x)$, is merely a restatement of the trivially evident property of null functions that the class of null functions is closed under addition. Similarly the equally important theorem which runs as follows:

If $y_1 = y_1(x)$ and $y_2 = y_2(x)$ are differentiable at x then the product function $p(x) = y_1(x)y_2(x)$ is differentiable at x, and its derivative p_x is furnished by the formula

$$p_x = (y_1(x))_x y_2(x) + y_1(x)(y_2(x))_x$$

is an immediate consequence of the fact that the class of null functions is closed under multiplication by bounded functions and under addition. Indeed,

$$\Delta p = y_1\Delta y_2 + (\Delta y_1) y_2 + \Delta y_1 \Delta y_2$$
$$= \{y_1 (y_2)_x + (y_1)_x y_2 + \nu_3\}\Delta x$$
where $\nu_3 = y_1\nu_2 + \nu_1 y_2 + (y_1)_x\Delta y_2 + \nu_1\Delta y_2$ is null at $\Delta x = 0$ (since Δy_2 is null at $\Delta x = 0$).

The simple observation that every linear function of x is differentiable at any value of x combined with the two properties of the operation of differentiation which we have just proved shows that any polynomial function of x

$$y(x) = c_0 + c_1 x + \ldots + c_n x^n$$

is differentiable at any value of x with derivative

$$y_x = c_1 + 2c_2 x + \ldots + nc_n x^{n-1} \quad .$$

The fact that any linear function of x, $y(x) = c_0 + c_1 x$, is differentiable at any value of x is evident since $\Delta y = c_1\Delta x$. Indeed we may write this relation in the form

$$\Delta y = (y_x + \nu)\ \Delta x,$$

where $y_x = c_1$ and ν is the zero constant function (of Δx). The fact that, for a linear function, Δy is the product of Δx by a constant enables us to phrase the definition of differentiability (which appears when written without words in the form $\Delta y = (y_x + \nu)\Delta x$) in a form which indicates more simply and more clearly than does the technical term limit the real meaning of the concept:

A function $y = y(x)$ is differentiable at a value x of the independent variable if $y = y(x)$ is nearly linear at x.

The signification of the phrase "nearly linear" is as follows: If $y = y(x)$ were linear, Δy would be the product of Δx by a constant, i.e., by a number which is independent of Δx (that this number is also independent of x is not of prime importance). We say that $y = y(x)$ is *nearly linear* when Δy is the product of Δx by a function of Δx which is *nearly constant,* i.e., which differs from a constant function of Δx by a function of Δx which is null at $\Delta x = 0$. That this constant function of Δx varies, in general, with x merely indicates that the linear function of x which *approximates* $y = y(x)$ at each value of x at which $y = y(x)$ is differentiable varies, in general, with x. This concept of a differentiable function of x being *nearly linear* leads naturally to the concept of the tangent to the graph of the function $y = y(x)$ at any point (x, y) of this graph (it being understood that the function $y = y(x)$ is differentiable at x).

One of the most important theorems of differential calculus is the theorem known as the rule of composite differentiation, or the chain rule. This theorem states that if $y = y(x)$ is differentiable at $x = a$ and if $w = w(y)$ is differentiable at $b = y(a)$ then $W = W(x) = w\{y(x)\}$ is differentiable at $x = a$ with derivative $W_x(a) = w_y(b) y_x(a)$. The proof is immediate when we write the definition of the concept of differentiability in the form $\Delta y = (y_x + \nu)\Delta x$. In fact, we are given that $\Delta y = (y_x + \nu)\Delta x$, $\Delta w = (w_y + \nu')\Delta y$ where ν' is null at $\Delta y = 0$ (and hence [why?] at $\Delta x = 0$). Hence, $\Delta W = \Delta w = (w_y y_x + \nu'')\Delta x$ where $\nu'' = w_y\nu + y_x\nu' + \nu'\nu$ is null at $\Delta x = 0$, proving the theorem. *Note*: In the usual proof in which y_x is defined as the limit of $\dfrac{\Delta y}{\Delta x}$ at $\Delta x = 0$, care must be taken to avoid the points $x \neq a$ for which $\Delta y = 0$, for the ratio $\dfrac{\Delta w}{\Delta y}$ whose limit defines w_y is not defined when $\Delta y = 0$; if y_x is zero at a, there may exist in every neighborhood of a, points at which $\Delta y = 0$. Thus the division by Δy introduces an unnecessary complication.

We conclude these remarks by pointing out that the definition of differentiability which appears in symbols as

$$\Delta y = (y_x + \nu)\Delta x$$

has the further advantage that it shows clearly the important role played by the differential. Δy consists of two parts, the first of which comes from the constant term y_x in the parenthesis $(y_x + \nu)$, and the second of which comes from the null part ν in this parenthesis. The first part is the *differential dy*:

$$dy = y_x\Delta x.$$

If $y_x \neq 0$ this may be termed, in a sufficiently small neighborhood of x, the principal part of Δy; but whether $y_x = 0$ or not, it is the part of Δy that comes from the constant term in the parenthesis $(y_x + \nu)$. Finally, the extension to the case of differentiable functions of more than one variable is evident. If $z = z(x, y)$ is a function of two independent variables (x, y), we say that $z = z(x, y)$ is differentiable at (x, y) if Δz may be written in the form

$$\Delta z = (z_x + \nu_1)\Delta x + (z_y + \nu_2)\Delta y$$

where z_x and z_y are independent of Δx and Δy and ν_1 and ν_2 are null functions of Δx and Δy at the point $(0, 0)$. The differential dz is the part of Δz that comes from the constant terms z_x and z_y in the parentheses $(z_x + \nu_1)$ and $(z_y + \nu_2)$:

$$dz = z_x\Delta x + z_y\Delta y;$$

and so on for differentiable functions of any number of variables.

The Concept of Integrability

Every student of calculus learns that a function $y = y(x)$ of a single real variable x is integrable over an interval $[a, b]$ over which it is defined if

$$\lim_{\delta \to 0} \sum_{i=1}^{n} y(\xi_i)\, \Delta_i x$$

exists and the value of this limit, when it exists, is known as the definite integral:

$$\int_a^b y(x)\, dx$$

of the function $y = y(x)$ from a to b. In the symbol $\lim_{\delta \to 0} \sum_{i=1}^{n} y(\xi_i) \Delta_i x$ it is understood that the interval $[a, b]$ is divided into n subintervals by means of the net of points

$$a = x_0 < x_1 < \ldots < x_{n-1} < x_n = b$$

(there being no real loss of generality in taking a to be less than b); $\Delta_i x$ is the length $x_i - x_{i-1}$ of the i^{th} of these subintervals; ξ_i is any point of this i^{th} subinterval, so that $x_{i-1} \leq \xi_i \leq x_i$, and δ is the greatest of the n numbers $\Delta_i x$. When the student is taught this concept of integrability and this definition of the definite integral of a function over an interval, he is supposed to be familiar with the concept of the limit of a function of a single independent variable at a given value of this independent variable, and the necessary question arises: Of what single variable is the sum

$$\Sigma = \sum_{i=1}^{n} y(\epsilon_i) \Delta_i x$$

a function? It would seem from the $\lim_{\delta \to 0}$ which precedes this sum that the independent variable is δ and that the definite integral is the limit at $\delta = 0$ of this function of δ (provided this limit exists); but this is obviously not the case, for Σ is not known when δ is given. It is necessary to know, in addition to δ, the points $x_1, x_2, \ldots, x_{n-1}$ which define the subdivision of the interval $[a, b]$ and also the points $\xi_1, \ldots, \xi_n$, one in each of the subintervals, before we can calculate Σ. That which is implied by the symbol $\lim_{\delta \to 0}$ is not the ordinary concept of the limit of a function of a single variable at a given value of this variable (or even the limit of a function of many variables at a given set of values of these variables). What is meant by the symbol $\lim_{\delta \to 0} \Sigma$ is the following: The collection of sums Σ is a collection of real numbers, i.e., a variable; if this variable has the property that the difference between a fixed number I and any value of the variable for which $\delta \leq$ a given number δ' may be made arbitrarily small by making δ' sufficiently small, we say that the variable (i.e., the collection of sums Σ) has the limit I at $\delta = 0$, and it is this "limit" that is the definite integral $\int_a^b y(x)\, dx$ *of* the function $y = y(x)$ over the interval $[a, b]$.

The concept of the definite integral of a given function $y = y(x)$ over a given interval can be explained without using the quite sophisticated idea of limit just described. All we have to do is to use the idea of the bounds, upper and lower, of a bounded variable. A variable is "bounded above" if there exists a number C such that every value of the variable $\leq C$. It follows from the definition of a real number that every variable which is bounded above possesses a least *upper bound* M; in other words, there exists a number M having the property that every value of the variable $\leq M$ while, no matter how small is the positive number δ, there exists a value of the variable $> M - \delta$. We term this least upper bound of the bounded variable simply its *upper bound*. Similarly, a variable which is bounded below possesses a greatest lower bound m which we term simply its *lower bound*. A variable is said to be *bounded* when it is bounded above and bounded below. Thus every bounded variable has associated with it two numbers, its upper and lower bounds. The first hypothesis we must make when we wish to define the integral of a function $y = y(x)$ over an interval $[a, b]$ is that $y = y(x)$ is bounded over $[a, b]$. It follows that $y = y(x)$ is bounded over any subinterval of $[a, b]$, and if $a = x_0 < x_1 < \ldots < x_{n-1} < x_n = b$ is any net on $[a, b]$, we denote by M_i and m_i, respectively, the upper and lower bounds of $y = y(x)$ over the subinterval $x_{i-1} \leq x \leq x_i$. Then we have associated with the net $a = x_0 < x_1 < \ldots < x_n = b$ the following two sums

$$S = \sum_{i}^{n} M_i \Delta_i x; \quad s = \sum_{i}^{n} m_i \Delta_i x,$$

and it is clear (why?) that if Σ is any *approximating* sum

$$\Sigma = \sum_{i}^{n} y(\xi_i) \Delta_i x$$

associated with this net then

$$S \geq \Sigma \geq s$$

Thus the sums S and s introduce a kind of order into the chaos of sums Σ; S and s are functions of the net $a = x_0 < x_1 < \ldots < x_n = b$, whereas Σ is not. But, although Σ is not a function of the net, we know that Σ lies between the two numbers S and s which are functions of the net.

If we add to any net on $[a, b]$ one or more additional points of subdivision we term the new net obtained in this way a *refinement* of the original net, and it is clear that the refinement of a net does not increase S nor diminish s. If, then, we have two nets N_1 and N_2 and we denote by N_3 the refinement of either of them obtained by superimposing the two nets, we have

$$S_1 \geqq S_3 \geqq s_3 \geqq s_2.$$

In other words, every $S \geqq$ every s, so that the variable whose values are the various sums S is bounded below; we denote its lower bound by B. Similarly, the variable whose values are the various sums s is bounded above; we denote its upper bound by β. Since every $S \geqq$ every s it is clear that $B \geqq \beta$ (why?). If $B = \beta$, we say that $y = y(x)$ is integrable over $[a, b]$, and we term the common value of B and β the integral $\int_a^b y(x)\,dx$ of the function $y = y(x)$ over the interval $[a, b]$. On the other hand, if $B > \beta$ we say that the function $y = y(x)$ is not integrable over the interval $[a, b]$.

The only question that remains is a practical one. How can one tell whether $B = \beta$ or not, and if we know that $B = \beta$, how can we determine the common value of B and β? It follows immediately from the definition of the bounds, upper and lower, of a bounded variable that $B = \beta$ when, and only when, we can find a net for which $S - s$ is arbitrarily small. Furthermore, it can be shown, without difficulty, that when $B = \beta$ all nets for which δ, the length of the greatest subinterval of the net, is sufficiently small have $S - s$ arbitrarily small. We shall say that a net is *sufficiently fine* when δ is sufficiently small. In this terminology, then, we have the following *criterion for integrability*: The function $y = y(x)$ is integrable over the interval $[a, b]$ if, and only if, $S - s$ may be made arbitrarily small by making the net on $[a, b]$ sufficiently fine.

Since, when $B = \beta$, their common value, namely, the integral $\int_a^b y(x)\,dx$ of the function $y = y(x)$ over the interval $[a, b]$, is bracketed between the two sums S and s for any net:

$$S \geqq \int_a^b y(x)\,dx \geqq s \;;$$

and since any approximating sum Σ is bracketed between the S and s of the net with which the approximating sum is associated, it follows that when $y = y(x)$ is integrable over $[a, b]$ the difference between its integral and all approximating sums Σ for nets which are sufficiently fine may be made arbitrarily small. This is the meaning of the usual definition which states that the integral is the limit, as $\delta \to 0$, of the approximating sums Σ.

In conclusion, we point out how easily the basic properties of the integral $\int_a^b y(x)\,dx$ are deducible from the definition of this integral as the common lower bound of the sums S and upper bound of the sums s. The roughest net on $[a, b]$ is that for which we make no subdivision at all; for this net $S = M(b-a)$ and $s = m\,(b-a)$ where M and m are, respectively, the upper and lower bounds of $y = y(x)$ on $[a, b]$. Since the integral $\int_a^b y(x)\,dx$ is (by its definition) bracketed between the S and s for any net we obtain the very useful *Theorem of the Mean* for definite integrals:

$$\int_a^b y(x)\,dx = \mu(b-a)\;;\quad m \leqq \mu \leqq M.$$

The additive property, with respect to the interval of integration, is evident. In fact if $[a, b]$ and $[b, c]$ are two intervals which are such that the terminal point of the first interval is the same as the initial point of the second interval, let us denote the upper and lower sums for any net on the first interval by S_1 and s_1, respectively, and for any net on the second interval by S_2 and s_2, respectively. Then $S_1 + S_2$ is an upper sum, and $s_1 + s_2$ a lower sum, for the interval $[a, c]$. Since $(S_1 + S_2) - (s_1 + s_2) = (S_1 - s_1) + (S_2 - s_2)$, it follows, from the criterion for integrability, that the integrability of $y = y(x)$ over $[a, b]$ and over $[b, c]$ guarantees the integrability of $y = y(x)$ over $[a, c]$. Furthermore, $\int_a^c y(x)\,dx \leqq S_1 + S_2$, and, since this holds for every S_1 and S_2, we must have (from the very concept of a lower bound) $\int_a^c y(x)\,dx \leqq \int_a^b y(x)\,dx + \int_b^c y(x)\,dx$ and, similarly, since $\int_a^c y(x)\,dx \geqq s_1 + s_2$, we have

$$\int_a^c y(x) \times dx \geqq \int_a^b y(x)\,dx + \int_b^c y(x)\,dx.$$

Hence $\int_a^c y(x)\,dx = \int_a^b y(x)\,dx + \int_b^c y(x)\,dx$.

On combining this additive property of the integral (with respect to the interval of integration) with the Theorem of the Mean we obtain at once the Fundamental Theorem of Integral Calculus:

The integral $\int_a^t y(x)\,dx$ is a differentiable function of t at every value of t at which $y(x)$ is continuous, its derivative being $y(t)$.

The proof of the important result that every continuous function is integrable is not suitable for a beginning course in calculus since it requires the sophisticated concept of uniform continuity. But the proof of the fact that every *monotone* function is integrable is extraordinarily simple. There is no lack of generality in taking the function to be nondecreasing; then, for any net, $M_i = y(x_i)$, $m_i = y(x_{i-1})$ and so

$$S - s = \sum_{i=1}^{n} \Delta_i y\, \Delta_i x \;\; (\text{where } \Delta_i y = y(x_i) - y(x_{i-1}) \geqq 0)$$

$$\leqq \delta \sum_{i=1}^{n} \Delta_i y = \delta\{y(b) - y(a)\}.$$

Hence $S - s$ may be made arbitrarily small by making the net sufficiently fine, and so the monotone function is integrable. Every function that the beginning student will meet is such that its interval of definition may be so subdivided that the function is monotone over each subinterval of the net. For example, any polynomial has this property, and so the beginning student can really prove that every polynomial is integrable (and determine, by means of the Fundamental Theorem, its integral). The function $\frac{1}{x}$ is integrable over the interval $[1, b]$,

where $b > 0$, and this fact furnishes, perhaps, the simplest *definition* of log x:

$$\log b = \int_1^b \frac{dx}{x};\ b > 0.$$

Instead of trying to prove that every continuous function is integrable, it seems better to state the theorem that every continuous function may be approximated uniformly over an interval, arbitrarily closely, by a polynomial. Once this is granted, the integrability of continuous functions follows immediately from the integrability of polynomials.

PRELIMINARY ANNOUNCEMENT OF THE CLEVELAND MEETING, DECEMBER 26–30, 1950

THE 117th Meeting of the American Association for the Advancement of Science, the Annual Meeting for the year 1950, will be a full-scale meeting—with programs in every principal field of science from astronomy and botany to zoology. All 17 of the Association's sections and subsections and more than 40 participating societies and organizations are completing plans for an aggregate of more than two hundred sessions. The Annual Science Exposition, in the Arena of Cleveland's Public Auditorium, it is indicated, will be larger than that of the New York Meeting.

Nearly all the sectional programs will be held in meeting rooms of the Auditorium, within short walking distance of the downtown hotels. Sections I-Psychology and Q-Education, however, will meet in the Statler, headquarters of the science-teaching societies, and Section F-Zoology probably will hold its symposium in the Hollenden, the headquarters of the four zoological societies. Except for some of the large public lectures, in the Auditorium, and demonstration sessions one afternoon on the campus of Western Reserve University, the public rooms of the hotels will serve the requirements of the societies.

There will be a considerable number of outstanding symposia. Most of these are scheduled for the latter part of the week, whereas most of the paper-reading sessions of the sections will be held the first part of the period. It has been possible to keep conflicts between programs in a given field to a minimum. The individual convenience and integrity of the sessions of each society are assured by the continuity of use of the same rooms in hotels where related societies are housed. At the same time, the advantages of the large diversified meeting are not lost. There will be joint programs and symposia in areas between scientific fields, and the bringing together of outstanding authorities and workers in diverse fields of science. In the Exposition, publishers, supply houses, microscope manufacturers, instrument-makers, and industrial concerns will exhibit their latest products or portray their technical accomplishments on a scale impossible at a smaller meeting in a single scientific field. Adjacent to the exhibit area will be the Main Registration, the Visible Directory of Registrants (enlarged to permit better alphabetization), the Annual International Photography-in-Science Salon sponsored by THE SCIENTIFIC MONTHLY and the Smithsonian Institution, and the Science Theatre, this year repeating programs throughout the week in a large room designed for projection and with a capacity of 678.

The list of special sessions or public lectures, such as the AAAS Presidential Address, and those sponsored by the Academy Conference, the British AAS, National Geographic Society, Scientific Research Society of America, and the Society of the Sigma Xi, will be augmented this year by the annual lecture of the United Chapters of Phi Beta Kappa.

An extensive series of tours to museums, laboratories, and industrial plants of the Cleveland area is being arranged. Some of these will be of particular interest to chemists and are being included as a part of the program of Section C.

An outline of the sectional programs and participating societies, arranged by scientific fields, and the personnel of the local committees, will appear in a subsequent issue.

RAYMOND L. TAYLOR
Assistant Administrative Secretary, AAAS

The Great Smoky Mountains—Their Geology and Natural History*

PHILIP B. KING and ARTHUR STUPKA

Mr. King is in charge of a party of geologists of the U. S. Geological Survey who are making a study of Great Smoky Mountains National Park in cooperation with the National Park Service and the Tennessee Division of Geology. He holds the position of geologist in charge of tectonic investigations on the Geological Survey and has written on the tectonics of the Southwestern states and the southern Appalachians. Mr. Stupka has been park naturalist of Great Smoky Mountains National Park since 1935, and was previously park naturalist of Acadia National Park. His observations and study in the Great Smokies have made him an authority on the natural history of the southern Appalachian Highlands.

THE Great Smoky Mountains lie in eastern Tennessee and western North Carolina, between the cities of Knoxville on the west and Asheville on the east (see index map, Fig. 1). The mountains are a segment of the divide that forms the boundary between the two states, and are a part of the Appalachian Highlands—that long belt of elevated country which extends through the Southeastern states from Virginia to Georgia. The mountains have long been poorly accessible from centers of population, have harbored a mountaineer culture, served as a refuge for wildlife, and retained many areas of virgin forest.

Referring to the Unaka Chain, of which the Great Smoky Mountains are a part, James M. Safford, one of Tennessee's pioneer geologists, wrote more than eighty years ago, "Its bald summits, its semi-arctic plants and balsam peaks, the magnificent scenery it affords; its roaring rapids and wild cascades; its game, and the trout of its cold streams, altogether make it an elysium" (1869, 22). These conditions are still largely true today.

Within the past few decades this mountain wilderness has been set apart for the American people as Great Smoky Mountains National Park. Establishment of the park was authorized by an act of Congress of May 22, 1926, and land has been acquired gradually by the states of Tennessee and North Carolina, with Federal aid, in addition to a contribution by John D. Rockefeller, Jr., through the Laura Spelman Rockefeller memorial. The park is 54 miles long, and its greatest width is 19 miles (Fig. 1). When completed it will comprise an area of about 500,000 acres, or about 780 square miles.

A mist or haze rises at times from the dense vegetation of the mountain valleys, and obscures even the lofty peaks of the range; from this "smokiness," no doubt, the name Great Smoky Mountains is derived. On its northern, or Tennessee, side the range projects in ramparts and massive bastions above much lower foothills, and forms the skyline on the south when viewed from Maryville, Sevierville, Newport, and elsewhere in the Tennessee Valley. On the southern, or North Carolina, side the mountain front is poorly defined, and innumerable ramifying and sharp-crested spurs extend out from the main divide. Thus from this direction the full sweep of the range is not visible, except from lofty overlooks in the Blue Ridge.

Many streams of the Appalachian Highlands originate in western North Carolina, east of the higher mountains, and flow in a curious fashion through the mountain barrier to join the Tennessee River, a part of the Mississippi River drainage. The valleys of two of these, the Big Pigeon and Little Tennessee rivers, terminate the Great Smoky Mountains on the east and west (Fig. 1), and separate them from other ranges of the Appalachian Highlands.

The Great Smoky Mountains include some of the highest land east of the Mississippi River. For 36 miles the main divide stands more than 5,000 feet above sea level, and sixteen of the peaks rise to

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altitudes of more than 6,000 feet, culminating in Clingmans Dome at 6,643 feet. The altitudes of the higher peaks exceed those of Mount Washington in New England (6,288 feet) and are only a little lower than Mount Mitchell (6,684 feet), farther east in North Carolina. From the summit of Mount Le Conte to the town of Gatlinburg, 6 miles away, there is a difference in altitude of more than a mile—a respectable declivity even by Western standards.

The Geological Story

The visitor to the Great Smoky Mountains sees at first the predominant forest and the shaded undergrowth, and is not immediately aware that the soils of the forest conceal a solid core of native rock. Later he notices here and there rocky cliffs and crests (such as the Chimneys, Fig. 2), and the great boulders, or "graybacks," that are strewn over the mountainsides and choke each rushing torrent. He may then perceive that the rock formations, although masked by soil and vegetation, have determined the fundamental features of the mountain landscape.

Many visitors ask: Are the Great Smoky Mountains the oldest mountains in the United States? The geologist is nonplused by the question, for he is aware of the ceaseless changes that take place on the face of the earth through the reaches of geologic time. Does the question ask whether the rocks that compose the mountains are the oldest? Does it refer to the folding and disturbance that one sees in the strata, which were undoubtedly associated with a former time of mountain making? Or does it refer to the topographic features we see today? The geologist therefore does not answer the question directly, but tells a story of the region in the following terms.

The first chapter that can be read in the rocks of the Great Smoky Mountains is that of *rock making*. Most of the rocks of the mountains belong to the Ocoee series (Safford, 1869, 183–98; King, 1949, 622–34)—a great mass of sedimentary rocks originally laid down as mud, sand, and fine gravel,

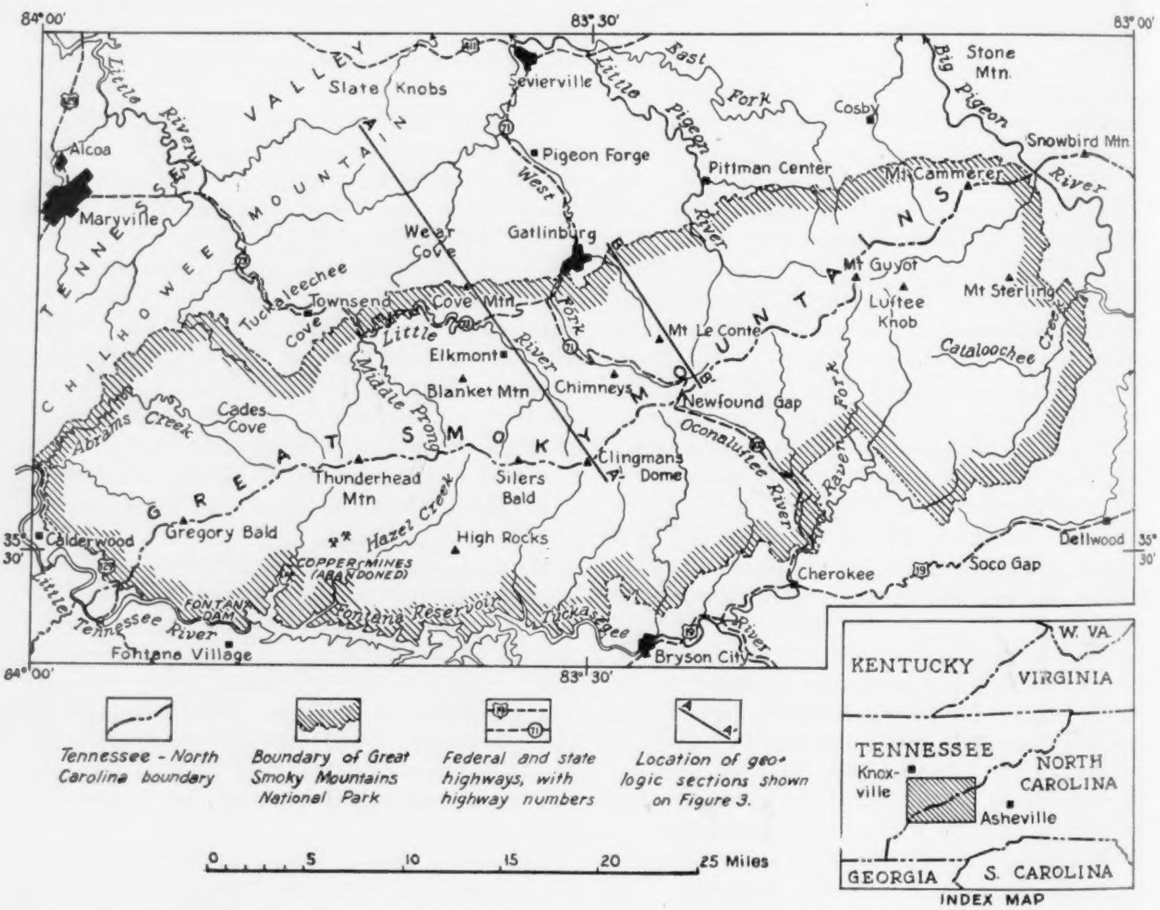


FIG. 1. The Great Smoky Mountains and vicinity, showing the location of many of the places indicated in the text and in the accompanying figures.

FIG. 2. The Chimneys, peaks of slate rising above State Highway 71. They are shown also at point *F* in Figure 5. (By P. B. King.)

which were spread as broad sheets, either on a level plain or on the bottom of a body of water. The series accumulated gradually, foot by foot, in successive strata, to a thickness of 20,000 feet or more. It was formed at a time now remote, probably before the Cambrian period of the Paleozoic era, or more than 500 million years ago. This was before life was abundant on the earth, and the Ocoee series, so far as known, contains no fossil remains of plants or animals.

Despite the antiquity of the rocks of the Ocoee series, they were not the oldest rocks in the vicinity, for they contain broken fragments of still older rocks (Keith, 1895, 2; 1904, 5). Some of the rocks of the Ocoee series, such as the unit marked "graywacke and conglomerate" on section *B B′* (Fig. 3), are made up of innumerable pebbles of quartz and feldspar; these pebbles were derived from the breaking apart, under the influence of the weather, of the individual crystals of an ancient granite mass. The conglomerate looks somewhat like granite and is composed of the same materials, but these materials have been broken up, transported, reconstituted in strata, and once more consolidated. The granite from which the conglomerates were derived probably stood as mountain ranges at the time when the Ocoee series was being formed.

Not all the rocks of the Great Smoky Mountains belong to the Ocoee series. To the northwest, in the Tennessee Valley, the rocks are of Paleozoic age, and they extend into the mountains, in a few places. Chilhowee Mountain, a narrow ridge that lies between the Great Smoky Mountains and the Tennessee Valley (Fig. 1), is formed of sa… other rocks of the Chilhowee group, being a part of the Cambrian system… vision of the Paleozoic. Many beds of t… contain worm tubes, or *Scolithus*, wh… oldest indications of life in eastern T… Cades Cove and Whiteoak Sink withi… and in adjacent Tuckaleechee and … (Fig. 1), are limestones belonging to… vician system, or second division of th… In Cades Cove, these limestones cont… pods, trilobites, and gastropods (Ne… 171–72).

Within the Ocoee series itself, other… been introduced at later times. In the … or the soil of the mountains one fre… blocks of white, milky quartz, locally… "flint rock." In the parent ledges fron… quartz was derived it lies in veins that … tures and crevices in the sedimentary … Ocoee series. Being less susceptible to… tion than the host rocks, the vein qua… vived as loose fragments long after th… closing material was destroyed by t… Penetrating the rocks of the Ocoee ser… the same manner as the veins are dil… of diorite, an igneous rock that entere… molten condition. Such dikes and sills … along Hazel and Eagle creeks in the sou… of the mountains. The copper deposit… formerly mined there (Fig. 1) may ha… troduced by hot solutions which ema… the diorite. Large masses of another ign… layered (or gneissic) granite, invade… series in the southeast part of the mou… the vicinity of Ravens Fork (Fig. 1). … granite may have been intruded in a m… tion; other parts may have formed by … of the host rocks with hot solutions, wh… in their recrystallization and replaceme…

The vein quartz, the diorite, and … gneiss were formed long after the accu… the sedimentary rocks of the Ocoee se… the rocks of the Cambrian and Ordovic… during a time of crustal stress and unre…

FIG. 3. Geologic sections in the northern… Great Smoky Mountains, showing the arrang… formations and the manner in which they h… formed. Stratification is shown by thin lin… breaks, are shown by heavy lines, the directi… ment being indicated by arrows. Section … from Chilhowee Mountain at the edge of t… Valley to the crest of the range at Clingmar… is by P. B. King and H. W. Ferguson. Secti… in greater detail the features along a line e… burg and Newfound Gap, and is by J. B. H… tion of sections is shown in Fig. 1.)

altitudes of more than 6,000 feet, culminating in Clingmans Dome at 6,643 feet. The altitudes of the higher peaks exceed those of Mount Washington in New England (6,288 feet) and are only a little lower than Mount Mitchell (6,684 feet), farther east in North Carolina. From the summit of Mount Le Conte to the town of Gatlinburg, 6 miles away, there is a difference in altitude of more than a mile—a respectable declivity even by Western standards.

The Geological Story

The visitor to the Great Smoky Mountains sees at first the predominant forest and the shaded undergrowth, and is not immediately aware that the soils of the forest conceal a solid core of native rock. Later he notices here and there rocky cliffs and crests (such as the Chimneys, Fig. 2), and the great boulders, or "graybacks," that are strewn over the mountainsides and choke each rushing torrent. He may then perceive that the rock formations, although masked by soil and vegetation, have determined the fundamental features of the mountain landscape.

Many visitors ask: Are the Great Smoky Mountains the oldest mountains in the United States? The geologist is nonplused by the question, for he is aware of the ceaseless changes that take place on the face of the earth through the reaches of geologic time. Does the question ask whether the rocks that compose the mountains are the oldest? Does it refer to the folding and disturbance that one sees in the strata, which were undoubtedly associated with a former time of mountain making? Or does it refer to the topographic features we see today? The geologist therefore does not answer the question directly, but tells a story of the region in the following terms.

The first chapter that can be read in the rocks of the Great Smoky Mountains is that of *rock making*. Most of the rocks of the mountains belong to the Ocoee series (Safford, 1869, 183–98; King, 1949, 622–34)—a great mass of sedimentary rocks originally laid down as mud, sand, and fine gravel,

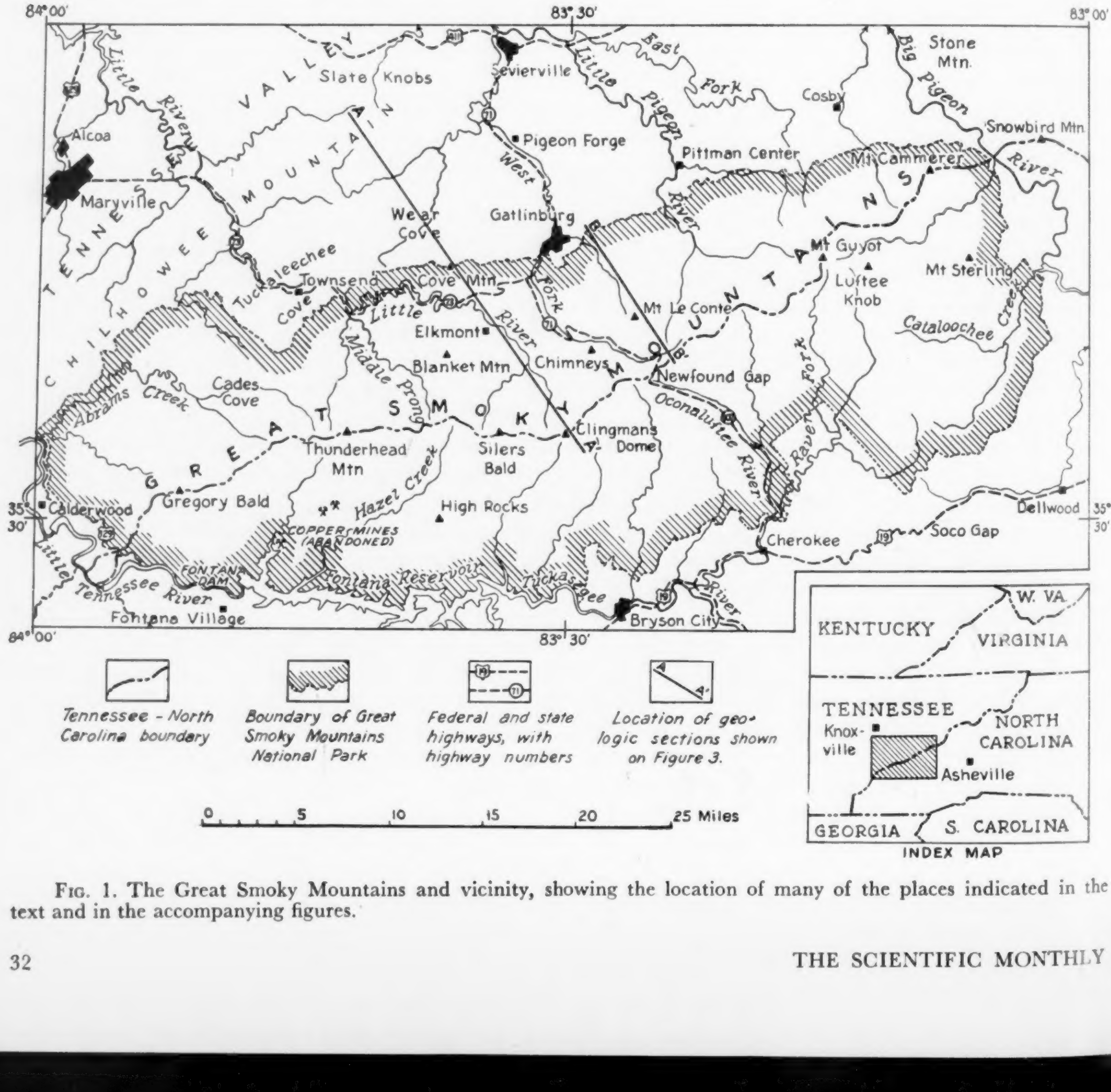


FIG. 1. The Great Smoky Mountains and vicinity, showing the location of many of the places indicated in the text and in the accompanying figures.

FIG. 2. The Chimneys, peaks of slate rising above State Highway 71. They are shown also at point *F* in Figure 5. (By P. B. King.)

which were spread as broad sheets, either on a level plain or on the bottom of a body of water. The series accumulated gradually, foot by foot, in successive strata, to a thickness of 20,000 feet or more. It was formed at a time now remote, probably before the Cambrian period of the Paleozoic era, or more than 500 million years ago. This was before life was abundant on the earth, and the Ocoee series, so far as known, contains no fossil remains of plants or animals.

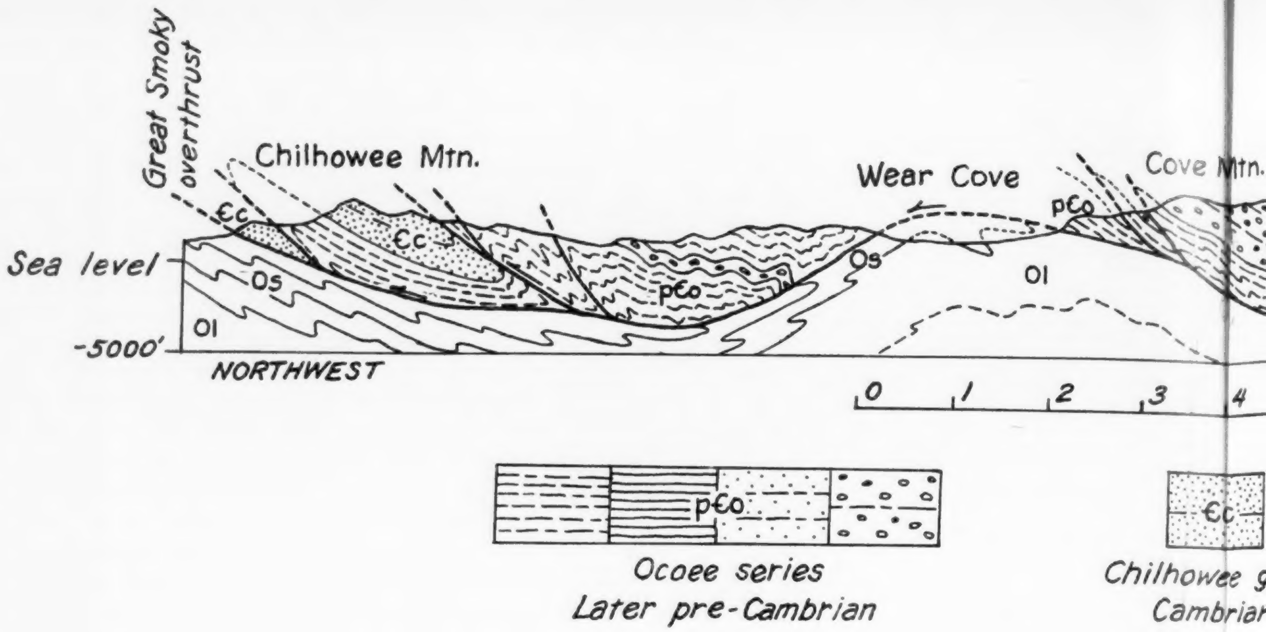
Despite the antiquity of the rocks of the Ocoee series, they were not the oldest rocks in the vicinity, for they contain broken fragments of still older rocks (Keith, 1895, 2; 1904, 5). Some of the rocks of the Ocoee series, such as the unit marked "graywacke and conglomerate" on section *B B′* (Fig. 3), are made up of innumerable pebbles of quartz and feldspar; these pebbles were derived from the breaking apart, under the influence of the weather, of the individual crystals of an ancient granite mass. The conglomerate looks somewhat like granite and is composed of the same materials, but these materials have been broken up, transported, reconstituted in strata, and once more consolidated. The granite from which the conglomerates were derived probably stood as mountain ranges at the time when the Ocoee series was being formed.

Not all the rocks of the Great Smoky Mountains belong to the Ocoee series. To the northwest, in the Tennessee Valley, the rocks are of Paleozoic age, and they extend into the mountains, in a few places. Chilhowee Mountain, a narrow ridge that lies between the Great Smoky Mountains and the Tennessee Valley (Fig. 1), is formed of sandstones and other rocks of the Chilhowee group, this group being a part of the Cambrian system, or first division of the Paleozoic. Many beds of the sandstone contain worm tubes, or *Scolithus,* which are the oldest indications of life in eastern Tennessee. In Cades Cove and Whiteoak Sink within the park, and in adjacent Tuckaleechee and Wear coves (Fig. 1), are limestones belonging to the Ordovician system, or second division of the Paleozoic. In Cades Cove, these limestones contain brachiopods, trilobites, and gastropods (Neuman, 1947, 171–72).

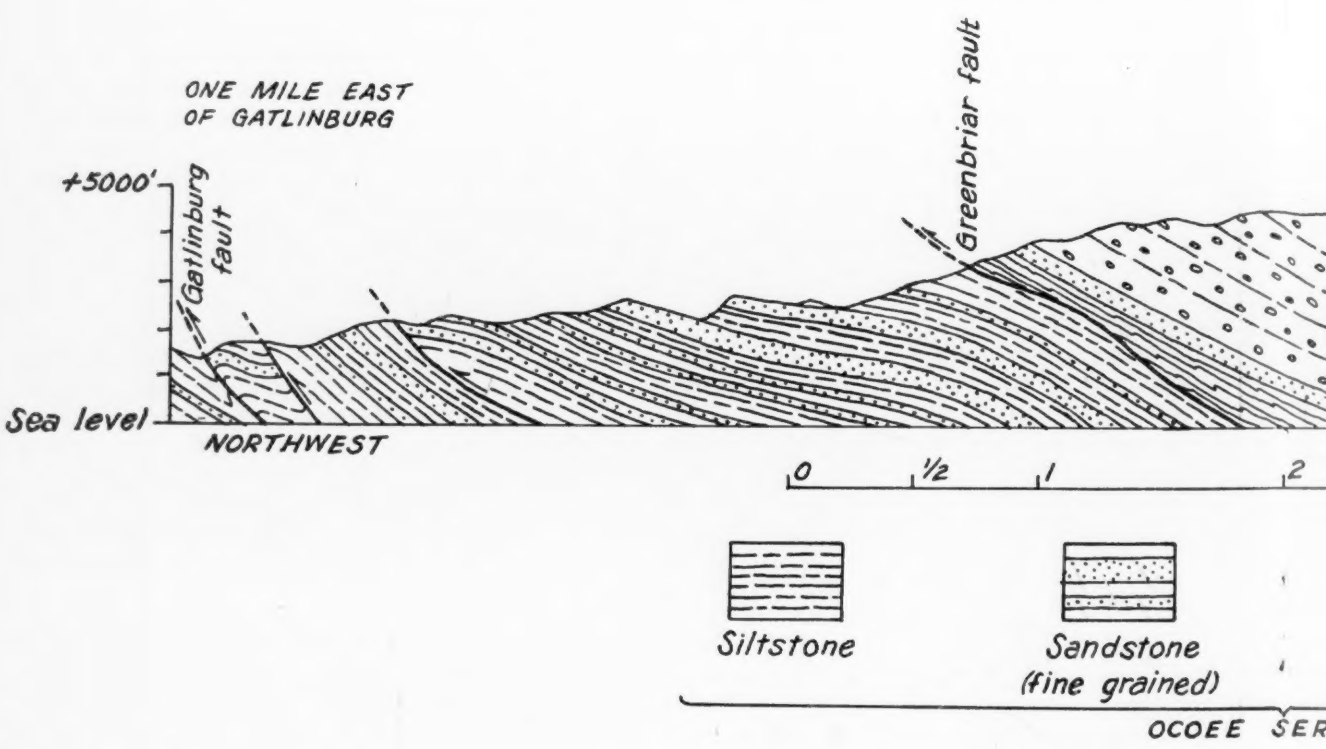
Within the Ocoee series itself, other rocks have been introduced at later times. In the stream beds or the soil of the mountains one frequently sees blocks of white, milky quartz, locally known as "flint rock." In the parent ledges from which the quartz was derived it lies in veins that follow fractures and crevices in the sedimentary rocks of the Ocoee series. Being less susceptible to disintegration than the host rocks, the vein quartz has survived as loose fragments long after the older enclosing material was destroyed by the weather. Penetrating the rocks of the Ocoee series in much the same manner as the veins are dikes and sills of diorite, an igneous rock that entered while in a molten condition. Such dikes and sills are common along Hazel and Eagle creeks in the southwest part of the mountains. The copper deposits that were formerly mined there (Fig. 1) may have been introduced by hot solutions which emanated from the diorite. Large masses of another igneous rock, a layered (or gneissic) granite, invade the Ocoee series in the southeast part of the mountains, as in the vicinity of Ravens Fork (Fig. 1). Part of the granite may have been intruded in a molten condition; other parts may have formed by the soaking of the host rocks with hot solutions, which resulted in their recrystallization and replacement.

The vein quartz, the diorite, and the granite gneiss were formed long after the accumulation of the sedimentary rocks of the Ocoee series, and of the rocks of the Cambrian and Ordovician systems, during a time of crustal stress and unrest that con-

FIG. 3. Geologic sections in the northern part of the Great Smoky Mountains, showing the arrangement of the formations and the manner in which they have been deformed. Stratification is shown by thin lines. Faults, or breaks, are shown by heavy lines, the directions of movement being indicated by arrows. Section *AA′* extends from Chilhowee Mountain at the edge of the Tennessee Valley to the crest of the range at Clingmans Dome, and is by P. B. King and H. W. Ferguson. Section *BB′* shows in greater detail the features along a line east of Gatlinburg and Newfound Gap, and is by J. B. Hadley. (Location of sections is shown in Fig. 1.)

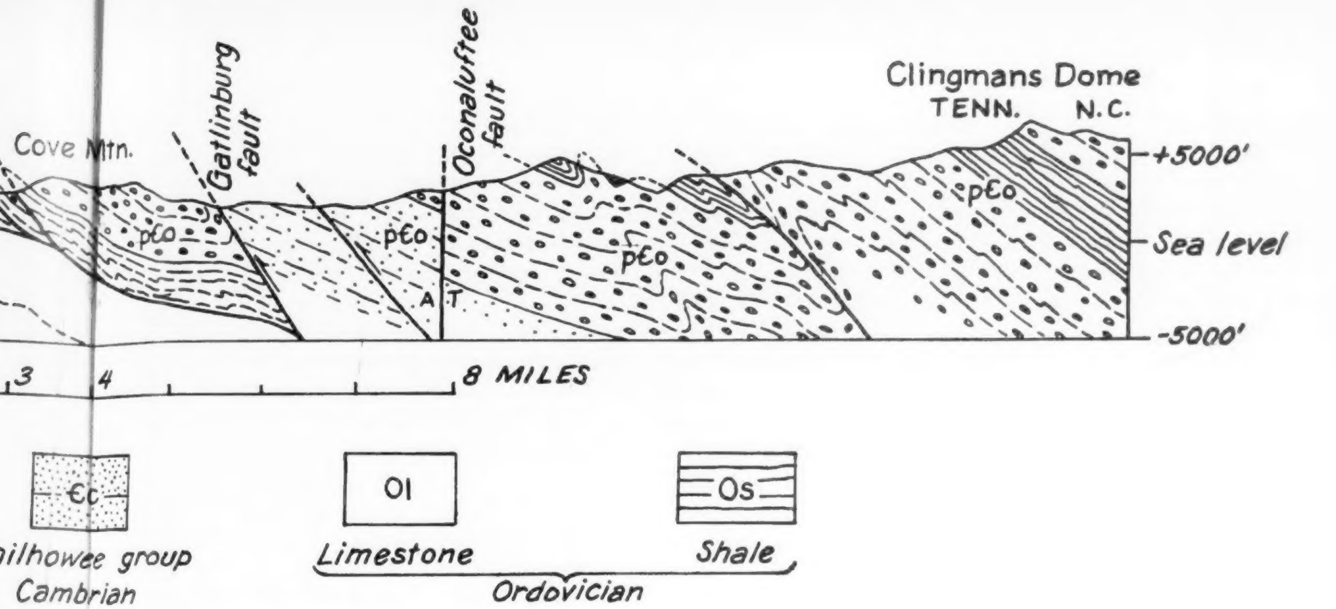


GEOLOGIC SECTION

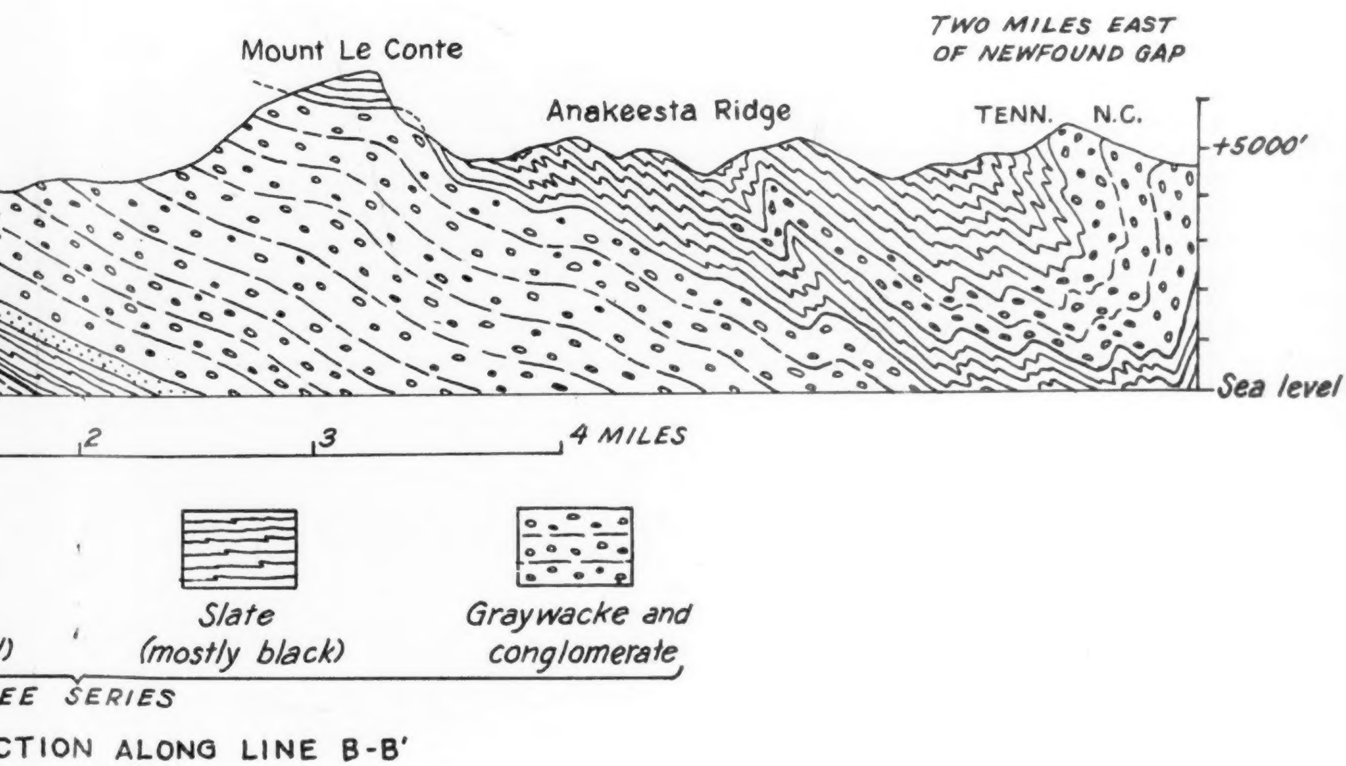


GEOLOGIC SECTION

FIG. 3.



ECTION ALONG LINE A-A'



CTION ALONG LINE B-B'

Fig. 3.

stitutes the next chapter in the history of the Great Smoky Mountains.

This next chapter may be termed the time of *mountain building*. One may observe in Figure 6 that the flanks of Mount Le Conte are marked by lines sloping to the right (south). These are lines of stratification in the conglomerate that forms the mountain. The stratification is shown more completely in section *B B′*, Figure 3, a geologic section as worked out by the geologist. The strata of the conglomerate were originally formed in a nearly horizontal position, and their present slope is a result of subsequent tilting. Elsewhere along the highways of the park, as at Newfound Gap (Fig. 1), one may see the strata standing on end, and at other places wrinkled into innumerable small folds and contortions. Further, one may see in many places, as along Tennessee Highway 73 between Townsend and Elkmont, that the slates are no longer composed of clay as they were when first deposited, but are made up largely of flakes of mica, formed by recrystallization (metamorphism) of the original clay constituents. The slaty rocks at many places in the southeast part of the mountains contain small crystals of garnet, likewise formed by recrystallization of the clay.

All these features are manifestations of powerful crustal movements that disturbed and changed the character and structure of the rocks of the Ocoee series. These movements took place in the later part of the Paleozoic era, or about 200 million years ago, and no doubt upheaved the southern Appalachian region into lofty mountain ranges. These mountains are the first of which we have record on the site of the present Great Smoky Mountains.

The mountain-making movements of later Paleozoic time are nowhere more strikingly exemplified than in Cades, Tuckaleechee, and Wear coves (Fig. 1). A view of one of these coves, or level-floored mountain valleys, is shown in Figure 4. Each cove is underlain by Ordovician limestones and associated shales like those in the Tennessee Valley to the northwest, and is surrounded by rocks of the Ocoee series, which project as ridges and mountains, and which overlie the limestones. These relations are illustrated by section *A A′* (Fig. 3), in which the Ordovician limestones and shales of Wear Cove are shown to be connected northwestward, beneath the Ocoee series, with similar rocks of the Tennessee Valley northwest of Chilhowee Mountain.

The Ordovician limestones and shales are younger than the rocks of the Ocoee series, and originally must have been laid down above it. The abnormal, or reversed, relations have been caused by the development of a great overthrust fault, designated the "Great Smoky overthrust" on section *A A′* (Keith, 1927), a gently dipping fracture along which the rocks of the Ocoee series have been pushed as a sheet, or plate, for many miles northwestward across the Ordovician and other Paleozoic rocks. By this overthrusting, the coves and their surroundings were covered by the mass of rocks of the Ocoee series.

Subsequent erosion succeeded in breaching the overthrust sheet in the cove areas, thereby creating "windows" through which one may look at the overridden Ordovician rocks beneath. Limestone is soluble and poorly resistant to erosion under the climatic conditions of the region, and the windows have therefore been enlarged into the level-floored coves, or valleys, that we now see.

The next chapter in the history of the Great Smoky Mountains was one of *mountain carving*, during which the mountains were gradually shaped into their present forms. After the end of the mountain building of Paleozoic time, the crust of the earth became quiet. Nothing comparable to the Paleozoic crustal disturbance took place again in the region. Subsequent history has been one of

FIG. 4. View of Cades Cove, a limestone valley in the Great Smoky Mountains, looking east-southeast. *D* is Thunderhead Mountain, and *E* is Blanket Mountain, also shown in Figure 5. (By P. B. King.)

erosion, by which the mountain ranges of Paleozoic time were worn down from their once lofty heights.

The Great Smoky Mountains are still a mountainous area today, not because of the incompleteness of the erosion process, but because the region has been subjected to leveling several times, each period of leveling being interrupted by renewal of the processes of erosion. From time to time in the past, erosion may have reduced the mountain area to a plain or near-plain, but each time streams eventually revived their activity and began cutting again to lower levels. These revivals of stream activity may have been caused by broad, gentle uplifts that raised the whole southern Appalachian Highlands above the base level of the sea.

When one stands on some vantage point on the summits of the Great Smoky Mountains, as on Cliff Top on Mount Le Conte (Fig. 5), one sees at first only a tangled confusion of peaks and ridges. Later, one observes that each ridge is separated from the next by a vast gulf, or valley, whose bottom is followed by a mountain torrent a thousand feet or so below. The present ridges and mountains are not caused by upheaval, but by erosion, whereby the valleys have been carved out of the same rock formations as those that still project above them. One may therefore conclude that the landscape of the Great Smoky Mountains is not made up so much of ridges rising between the valleys as of valleys cut between the ridges.

The ridge summits of the Great Smoky Mountains vary in height from place to place by hundreds of feet, yet the crests in each neighborhood rise to more or less the same height. If, in one's mind's eye, each deep intervening valley in the view shown in Figure 5 were filled to the level of the adjacent ridges, a hilly or rolling topography would be produced, with here and there a higher summit projecting above the rest. Whether such a surface ever existed is perhaps conjectural, but if it did it represents the earliest recorded pause in the long chapter of downcutting.

Remnants of another plain formed at a later time are visible at a much lower level in the foothills along the north side of the Great Smoky Mountains. As seen in Figure 6, the top of each foothill ridge stands at nearly the same height as the others, although the intervening valleys are cut to depths of hundreds of feet below them. These ridge tops seem to have been formed during a second pause in downcutting, which was again interrupted by the carving of the present stream valleys.

A still later chapter—or perhaps one might term it an appendix—in the history of the Great Smoky Mountains has to do with the *ice ages of Pleistocene time*. The Pleistocene epoch, with its succession of ice ages and intervening times of more moderate conditions, endured for possibly half a million years, and ended perhaps 20,000 years ago. It is thus a mere yesterday when compared with the geologic history already set forth, yet while it endured it imparted to North America a very different aspect from that before or afterward. Ice sheets spread southward over the continent, extending as far as the Ohio River, and the land to the south had a more rigorous climate than now.

The Great Smoky Mountains were well south of the region of the ice sheets, and they seem never to have possessed any glaciers. The time of mountain carving just described took place largely in the Tertiary, the period immediately before the ice ages. The gross features of the mountains were therefore much the same during the ice ages as at present, but during that time they were modified in many details.

Some of the steep mountain valleys well up toward the summits are covered by angular boulders of great size, which have been broken from rock ledges higher on the slope. None of these boulders seem to be breaking off, or to be sliding or rolling down the slope today, for they are overgrown by forest, and are decayed and lichen-covered. Farther down, near the bases of the mountains, the floors of many of the valleys are studded with other boulders, some as much as 30 feet in diameter and miles from their source, which the streams now flowing there seem unable to move. One may infer that these various boulder deposits are relics of a former time, and were produced by processes no longer at work in the region.

These processes may have been at work during the Pleistocene. The accumulations of angular boulders on the higher slopes resemble those now forming in alpine and subarctic environments above timber line (Denny, 1949). All the mountains of the Southeastern states are below timber line today, and timber line appears only farther north, as on Mount Washington in New England. During the Pleistocene, however, those ridges of the Great Smoky Mountains above 4,000 or 5,000 feet may have been bare of forest, a land of snow fields and naked rock. Projecting rocks were then riven by frost action, producing boulder fields on the slopes below. Boulders accumulated in the valleys to such an extent that they could not be removed by the streams, although they were urged forward slowly by the freezing, thawing, and heaving of the clays that enclose them.

In the Great Smoky Mountains, the story of *the*

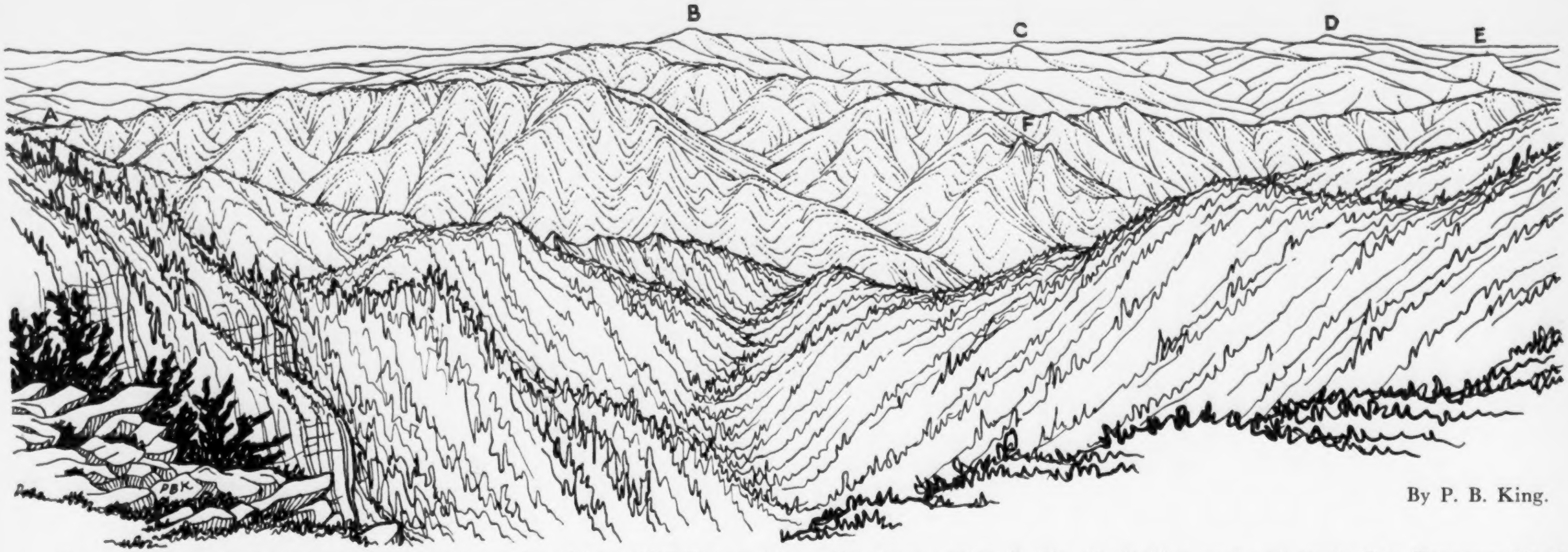


FIG. 5. Crest of the Great Smoky Mountains as viewed from Cliff Top on Mount Le Conte (point *H*, Fig. 6), looking west and south. The Tennessee-North Carolina state line is defined by Points *A, B, C,* and *D*. Point *A* is Newfound Gap; *B*, Clingmans Dome; *C*, Silers Bald; *D*, Thunderhead Mountain; *E*, Blanket Mountain; *F*, the Chimneys.

TABLE 1

Geological Story of Great Smoky Mountains

Chapter in Geological Story	Events (oldest at top)	Where Features Produced by Events May Be Seen	Geologic Periods and Eras	
ROCK MAKING	Granitic rocks raised into mountains	Near Great Smoky area, but location unknown	PRE-CAMBRIAN	
	Making of Ocoee series, by deposition of waste from granitic mountains on a flat plain or in a body of water	Ocoee series forms present high ridges of Great Smoky Mountains		
	Deposition of sandstones and other rocks of Chilhowee group	Chilhowee group forms Chilhowee Mountain, northwest of Great Smoky Mountains	Cambrian	PALEOZOIC
	Deposition of other formations, not mentioned here	Exposed in Tennessee Valley		
	Deposition of limestones and shales	Exposed in Cades, Tuckaleechee, and Wear coves, and in Tennessee Valley	Ordovician	
	Deposition of other formations, not mentioned here	Exposed in Tennessee Valley	Silurian, Devonian, and Mississippian	
MOUNTAIN MAKING	Formation of first mountains in southern Appalachian area: Folding of Ocoee series and younger rocks, metamorphism of Ocoee series, thrusting of Ocoee series northwestward along Great Smoky overthrust	Manifestations of folding, metamorphism, and thrusting are visible throughout the Great Smoky Mountains and Tennessee Valley	Probably during Pennsylvanian and Permian	
	Introduction of vein quartz, diorite, and gneissic granite; deposition of copper ores	Diorite, gneissic granite, and copper ores in south part of Great Smoky Mountains		
MOUNTAIN CARVING	Prolonged erosion of newly raised mountains, but no record preserved	Land surface of time was above tops of present mountain summits	Triassic, Jurassic, and Cretaceous	MESOZOIC
	Carving of a hilly or rolling surface	Remnants preserved on present mountain summits		
	Renewed downward cutting of streams	Deep valleys which dissect high mountain area	Tertiary	CENOZOIC
	Carving of plain along north foot of mountains	Remnants on top of foothill ridges		
	Renewed downward cutting of streams to approximately present levels	Lower slopes of present valleys		
ICE AGES	More rigorous climate than now; mountain summits and higher ridges at times above timber line; formation of boulder deposits by frost action	Boulder deposits on mountain slopes and in valley bottoms	Pleistocene	
TIME AFTER THE ICE AGES	Development of present conditions; amelioration of ice-age climate; growth of heavy vegetation on mountains		Recent	

time after the ice ages, the Recent epoch of geological terminology, is mainly that of development of the modern plant and animal life of the region. The geological story that already has been described is summarized in Table 1 (p. 39).

Natural History

Within the Great Smoky Mountains National Park a diversified animal life finds sanctuary. Here are found more than 50 kinds of furbearers, 200 birds, 80 reptiles and amphibians, 80 fishes, and a large group of insects and other invertebrates. Although the coming of the white man has brought about, directly or indirectly, the extirpation of certain large mammals, the number of small-sized and medium-sized species has probably changed but little. Black bears may be as prevalent in these mountains today as when the country was first settled, and they, along with such animals as bobcats, red and gray foxes, ravens, wild turkeys, ruffed grouse, and duck hawks, serve to preserve the wilderness character of this national park.

Whereas the more or less dense plant cover that prevails throughout these mountains is an obstacle to studying their geological features, it is this practically uninterrupted mantle of vegetation that makes the area outstanding. Of the approximately 1,300 species of flowering plants, 131 represent native trees—a greater number than is to be found in all of Europe. Various botanical surveys made within the park have shown that the nonflowering plants occurring there include about 50 ferns and fern allies, 330 mosses and liverworts, 230 lichens, and 1,800 fungi. Excepting the Florida peninsula, few if any areas in the eastern United States are as rich, botanically speaking.

Perhaps more so than in most regions, the flora of the southern Appalachian Highlands is deeply

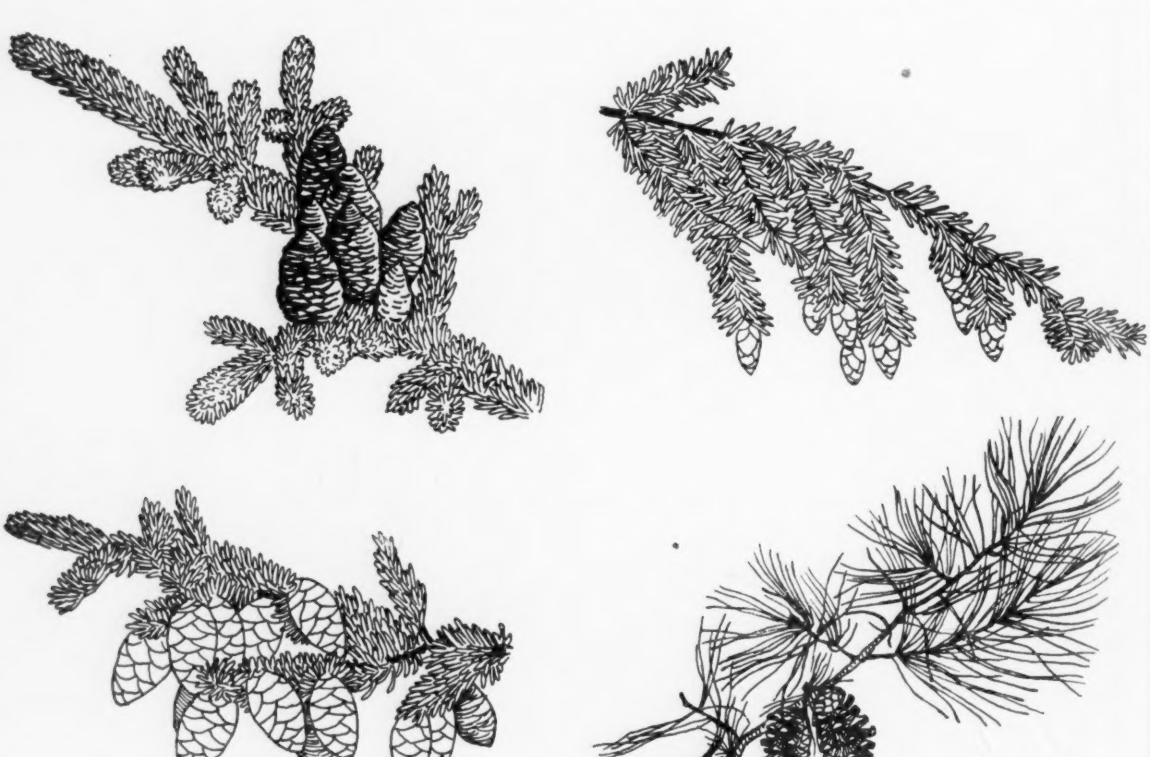


FIG. 7. Conifers of the Great Smoky Mountains. Upper left, Fraser's fir or balsam (*Abies fraseri*); lower left, red spruce (*Picea rubens*); upper right, Canada hemlock (*Tsuga canadensis*); lower right, pitch pine (*Pinus rigida*). Conifers on left are largely restricted to altitudes above 5,000 feet and are near the southern limits of their range; their more typical development is in the northern United States and southern Canada. Conifers on right occur at lower altitudes and are widely distributed in the southern Appalachian Highlands. (By J. D. Chaffin and John Scherer.)

rooted in the past, and provides a link with the bygone eras of geologic time. The flora of North America during the Tertiary showed a widespread uniformity, but during the unfavorable climatic conditions of the succeeding Pleistocene ice ages many species of plants were eliminated in the Northern and Western areas. Conditions in the southern Appalachian Highlands during the ice ages were in general less disturbed, so that this region harbored and preserved much of the Tertiary flora that was elsewhere destroyed. The region contains some of the oldest living plant species in the eastern United States.

> It seems reasonable to conclude . . . that the virgin hardwood forests of the Great Smoky Mountains National Park are the finest example of temperate Tertiary forests to be found anywhere in the world, except probably in eastern Asia. This much is certainly true, a botanist familiar with the modern flora of the cove hardwood forests of the Smokies would find himself "at home" among the temperate forests of the Miocene and later Tertiary, could he be transported back in time. The principal difference would be the presence in the [Miocene] forest of such temperate trees as *Sequoia* and *Ginkgo,* now very restricted (Cain, 1943, 233).

Like many generalizations, the one regarding the southern Appalachians as a haven for plant life requires modification in detail. Geological evidence indicates that climatic conditions in the Great Smoky Mountains were not unmodified during the ice ages; at times, for example, the higher ridges may have stood above timber line. Although living conditions in the region were broadly more favorable than those to the north and west, nevertheless they may have fluctuated. Such fluctuations resulted in many migrations and modifications of plant life in the southern Appalachian Highlands during the Pleistocene epoch (Deevey, 1949, 1,365–75). One indication of such migrations is the occurrence of spruce and fir forests on the higher summits of the southern Appalachian Highlands. One may suppose that these Northern plants spread southward into this region during the ice ages, and that their distribution in the region varied during the course of time under the same influences as those that determined the lowering and raising of the timber line.

The spruce and fir forests form a dark, somber growth that has earned for the ridges that bear them the local denomination of "black mountains." Two of the species (*Abies fraseri* and *Picea rubens*) are illustrated on the left-hand side of Figure 7, and the manner of growth on the steep mountain slopes is shown in Figure 8. Spruce and fir forests dominate at altitudes above 5,000 feet in the eastern half of the Great Smoky Mountains; they come to an end a few miles west of Clingmans Dome and are

FIG. 8. Red spruce (right) and dwarf rhododendron (above, left), growing on steep mountain slopes carved from slate. On Alum Cave trail on southwest slope of Mount Le Conte at an altitude of about 6,000 feet. (By Irving Fromer.)

absent farther south and southwest in the Appalachian Highlands. Botanists have found that more than half of the woody plants that occur in these forests are Northern species of the so-called Canadian zone, which reaches its southernmost extension in the Great Smoky Mountains. It is of interest that in the half-hour drive from Gatlinburg, Tennessee, or Cherokee, North Carolina, at the north and south edges of the mountains, respectively, to the crest of the range at Newfound Gap, there is a change in vegetation comparable to that seen by traveling a thousand miles northward.

Although most of the Great Smoky Mountains are forested, small areas on some of the summits are bare of trees, or "bald," as they are locally described.

Although treeless, the balds are not wanting in ver-

dure; supplied often with a good, though not deep, soil, they abound in grasses, ferns, and small shrubs, several of which belong to a far more northern climate than is found in the valleys below. During the summer, the clouds, in which they are often buried, keep them moist, and supply with water the ice-cold springs which are frequently found around their edges, much to the comfort and relief of the mountain-climbers who visit them (Safford, 1869, 34).

The balds do not indicate timber-line conditions, for near-by forested summits stand as high or higher. One is tempted to think of them as relics of some former climatic period, now partly engulfed in the prevailing forest, but their true explanation is elusive. They have certainly been maintained by exposure to prevailing winds, and to some extent during the last century, by man, who used them as a summer pasturage for stock.

Considerably different are other open areas on the ridge crests, the "heath balds," locally known as "laurel slicks." From a distance they appear to be a smooth, grassy carpet; they are in reality an almost impenetrable, head-high tangle of rhododendron, mountain laurel, and other members of the heath family, some of which are illustrated in Figure 9. Probably no individual laurel slick is very old. They seem to have originated from removal of the forest cover by fire, windfall, or landslide, and they are continually being reclaimed by the encroaching forest. They assume their most spectacular appearance in June when the predomi-

FIG. 9. Members of the heath family in the Great Smokies. Upper left, mountain laurel (*Kalmia latifolia*); center, Catawba rhododendron (*Rhododendron catawbiense*); lower right, flame azalea (*R. calendulaceum*). The first two have evergreen leaves and occur together in the heath balds, or laurel slicks, that form the crests of many ridges. The third is deciduous and is common in the grass balds of the mountaintops. (By J. D. Chaffin and Irving Fromer.)

nant Catawba rhododendron is covered with its rose-purple blossoms.

Under the influence of the present favorable climate, and free of interference by man, the forest trees of the Great Smoky Mountains attain great size. Table 2 shows some of the maximum circumferences observed; the figures were compiled from the records of the National Park Service.

TABLE 2

MAXIMUM OBSERVED TREE SIZES IN GREAT SMOKY MOUNTAINS

Common Name	Species	Circumference
Tulip tree	*Liriodendron tulipifera*	24 ft.
Canada hemlock	*Tsuga canadensis*	19 ft. 9 in.
Cucumber tree	*Magnolia acuminata*	15 ft. 3 in.
Yellow buckeye	*Aesculus octandra*	15 ft. 11 in.
Yellow birch	*Betula lutea*	14 ft. 1 in.
Red spruce	*Picea rubens*	14 ft. 1 in.
Mountain silver bell	*Halesia monticola*	11 ft. 9 in.
Fraser magnolia	*Magnolia fraseri*	7 ft. 7 in.
Fraser fir (balsam)	*Abies fraseri*	6 ft. 7 in.
Sourwood	*Oxydendrum arboreum*	6 ft. 4 in.
Allegheny serviceberry	*Amelanchier laevis*	6 ft. 2 in.
American mountain ash	*Sorbus americana*	5 ft. 6 in.
Pin cherry	*Prunus pennsylvanica*	4 ft. 11 in.

The observer best learns the natural history of the Great Smoky Mountains by studying it throughout the year, and seeing the changes in the plant and animal life with the passing of the seasons (Stupka, 1943). The flowering season is a long one, with sometimes only a month or two separating the late flowers, such as witch hazel, from the early bloomers, such as streamside alders. Then, too, certain plants that come into bloom in early spring at lower altitudes may be found in flower eight to ten weeks later along the crest of the main range.

April and May is the time of greatest blooming of the wild flowers of the forest floor, such as violet, phacelia, trillium, and many others; and of many trees, such as dogwood, serviceberry, and silver bell. Early to middle June marks the height of bloom of the spectacular Catawba rhododendron of the laurel slicks, and late June the blooming of the brilliant flame azaleas of the high grass balds (Fig. 9). The Turk's-cap lily, which may attain a height of 7–8 feet, reaches its peak of bloom during the second or third week of July. In mid-October, when the year begins to wane, the leaves of the hardwood trees change their color, and transform the mountainsides into variegated carpets of reds and yellows. By November, most of the hardwood leaves have fallen, and their groves are drab and dull, but colors during the succeeding winter are afforded by the evergreen leaves of the rhododendron, laurel, holly, and various conifers, and by the gleaming snow, which spreads over the whole mountains after a fall, and may linger for weeks on the north slopes, shaded by the low winter sun.

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The Limitations of Mechanistic Methods in the Biological Sciences

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The author, who received his M.D. degree from the University of Utrecht in 1930, has done research in endocrinology and has been on the psychiatric staff of several institutions. At present he is engaged in the private practice of psychiatry and is psychiatrist-in-charge of the Stamford Clinic of the Connecticut Commission on Alcoholism.

WHETHER mechanistic principles suffice for our understanding of the living organism is one of the central problems in biology. Some scientists hold that only these methods are capable of erecting biology as a true science; others claim that nonmechanistic principles are needed in biology. The reason for this difference in opinion is that one can set out to describe the living organism from two totally different viewpoints. If one wants to study biological phenomena that can be isolated from the rest of the organism, mechanistic methods of description and explanation are eminently successful. Physiological chemistry, for instance, with its highly important clinical applications, is an achievement of mechanistic methods applied to certain biological phenomena.

If, however, one seeks to understand the organism as a whole, mechanistic methods fail, because one needs holistic principles to understand the organism from this viewpoint. These principles can be delimited from mechanistic methods if one compares the temporal structure of various biological phenomena with the temporal structure of movement of inert matter. One can establish two modalities of temporal integration by comparing movement of inert matter with certain biological phenomena. On the basis of these two modalities of temporal structure, one can distinguish between mechanistic principles, applicable to inert matter, and holistic principles, applicable to living organisms.

Parallel to the differences between mechanistic and holistic methods one can differentiate between a pluralistic and a holistic approach toward reality in general and toward the organism in particular. Isolated phenomena, abstracted from the totality of the organism, are observed objectively by extrospection with the methods of the mechanistic natural sciences. Holistic phenomena are understandable through introspection (which statement will be substantiated by the analysis of the temporal structure of voluntary movements). Introspection stands in the same relationship to holistic principles as extrospection to mechanistic methods.

Mechanistic principles can be compared with holistic principles by an analysis of the temporal structure of movement, since this phenomenon is exhibited by both inert matter and living organisms. Living organisms display automatic and voluntary movements; we shall therefore discuss three modalities of movement by means of three examples.

Mechanics

In Galileo's time it was impossible to study free fall quantitatively because clocks did not run fast enough. "The only methods known for measuring time were by sundial, by burning candles or oil-lamps, by sand-glasses and water-clocks, and by very crude mechanical clocks. Galileo improved the water-clock in a very ingenious way, by letting water drip into a receiver and then weighing the amount which had fallen with great accuracy, but the times to be measured were still uncomfortably short. Galileo accordingly slowed his experiments down, by substituting a slow roll down a gentle slope for the rapid vertical fall, in the belief that

the same laws must govern both. . . He set up a gently sloping plank, some 12 yards in length, and made polished (bronze) balls roll down a narrow groove cut into it. With this simple apparatus he was able to verify his conjecture that the speed of fall increased uniformly with the time—the law of 'uniform acceleration.' "[1,2]

From the standpoint of scientific methods these experiments are, in essence, the determination of the position of the bronze ball before it fell, the determination of its position after it had fallen, and the correlation of the distance between these two positions with the amount of water that ran out of the water clock during the interval delimited by the two positions. For our purpose, it is important to recognize what becomes of movement when this phenomenon is treated with the methods of classical mechanics: the description of movement is reduced to the measurement of successive positions, and movement itself is eliminated.

For the quantitative description of movement one needs at least the following three aids: a Cartesian coordinate system, a measuring rod, and a clock. With these, and with auxiliary mathematical methods that need not be considered here, one can reduce the phenomenon of movement to a succession of positions. One relinquishes the phenomenon by reducing it to a succession of positions, but this is not a loss without compensation: one is able to predict future positions of bodies from their past positions, and this prediction is a tremendous gain. If one understands how the state of motion of a body in a past position causes the state of motion of that body in its present position, then one can also understand how its present state of motion causes its state of motion in a future position. The mechanistic natural sciences are able to predict the future state of motion and the future position of bodies by the reduction of movement to a succession of positions with coordinate system, measuring rod, and clock.

Application of Mechanistic Methods in Physiology

A certain group of phenomena observed in the living organism can be studied with mechanistic methods not only with great practical success, but also without raising problems of scientific method. Such phenomena can be isolated from the rest of the organism; e.g., heart action, respiration, liver function, reflex activities of the nervous system. The totality of the organism is eliminated as much as possible from these isolated, partial functions, allowing them to be studied by means of coordinate system, measuring rod, and clock. According to Goldstein,[3] one can observe such isolated phenomena in the physiological experiment and in pathological states: "Isolation is given either in the artificial disconnection of a part from the organism, which part should not enter into the reaction, or, in the separation of certain parts due to illness. There is a parallel between experimentally produced phenomena and pathological symptoms insofar as isolation plays a role in the emergence of both types of phenomena."

In order to focus the discussion on a specific example of isolation, one might analyze the description of the tremor of paralysis agitans with physiological methods. The physiologist, wishing to describe these movements quantitatively, straps the patient's arm to a frame, connects the moving finger with a mechanism which writes a measurable record on a kymograph, while a time-writing device marks suitable intervals underneath the curve. Obviously, he uses the same descriptive methods as the physicist, namely, coordinate system, measuring rod, and clock. Just as the movement of particles of inert matter is described by measuring successive positions of such particles, just so is the tremor reduced to a succession of positions on the kymographic record. Both mechanics and physiology break movement up into a succession of positions.

The parallel between mechanics and physiology goes beyond methods of description, as the causal explanations in both fields have many similarities, too. We postulate that movement of one particle is the cause of movement of another particle in the world of inert matter; therefore, when movement is observed one looks *backward in time* to find the movement which was its cause. In the case of automatic movements one relates externally observed movements to physical, chemical, electrical, and colloid-chemical processes within the central nervous system. These neural processes are prior in time to the tremor, no matter how short the time interval between internal process and external movement actually is; therefore, one looks *backward in time* to find the processes which cause the tremor, just as the physicist looks backward in time to find the cause of movement of a particle of inert matter. One may conclude, then, that the methods of description and explanation in physiology are quite similar to the methods of classical mechanics.

So long as the physiologist studies movement that can be isolated from the rest of the organism to a large extent (such as automatic movements), mechanistic principles of description and explanation are quite adequate. The study of voluntary motility with purely physiological methods, how-

ever, comes up against rather formidable obstacles, because this modality of movement has characteristics that defy description and explanation with mechanistic principles. These specific characteristics of voluntary movements derive from their organization in time. The description of the temporal organization of voluntary movements calls for nonmechanistic principles. Of course it is possible to apply mechanistic principles in this field, but the specific temporal structure of these movements is thereby distorted, since this leads to their breaking up in stretches, delimited by stationary positions. Nonmechanistic, or holistic, principles are necessary in biology in order to give an adequate account of the temporal organization of the total organism.

Mechanistic Methods and Holistic Principles

The physiological, mechanistic description of a Parkinsonian tremor is quite adequate, because the movements do not contribute to the totality of the organism. Their isolated position is expressed in their temporal structure. Movements of the total organism are always goal-seeking, future-striving, whereas the tremulous limb lacks these temporal and conative characteristics, because it simply goes from position to position, without purpose-striving, without projecting into the future. Mechanistic methods are applicable to those biological phenomena that lack the temporal integration characteristic of activities of the total organism.

As an example of an activity performed by the organism as a whole one might study the normal gait from the viewpoint of its temporal structure. Since one cannot compare Parkinsonian tremor with gait, we shall compare spastic gait with normal gait and, more specifically, how a normal person and how a spastic patient walk on the horizontal and on stairs. The spastic patient begins by stopping at the top of the staircase, then he puts his left foot on the first step and carefully lowers his right foot onto the same step; there he comes to a short resting position. The same sequence is repeated on each step, until he is downstairs. The movement "walking downstairs" is broken up into as many positions as there are steps on the stairway.

A normal, nonspastic person walks downstairs in a very different fashion: he does not stand still at the top of the stairs, but either foot immediately finds the first step, so that walking on the horizontal plane fluently intermeshes with walking downstairs. As soon as the left foot, for example, has found the first step, where it is in a very short resting position, the left leg begins to bend and the right foot prepares to move onto the second step, in the same period that the left foot rests on the first step. The left foot immediately leaves the first step as soon as the right foot has arrived on the second step and moves onto the third step while the right foot is in its resting position. Arrived on the last step, the normal person prepares to walk on the horizontal, so that there is no break of his movement at the bottom of the stairs.

Walking downstairs is one uninterrupted, unitary movement, executed as a whole. To be sure, the left foot rests for a very short time on each odd-numbered step and the right foot on each even-numbered step, and it is possible, therefore, to break this movement up into stretches of movement, delimited by positions, after the mechanistic manner of describing movement. But if one tries to force this movement into the framework of mechanics, the crucial point that differentiates the normal gait from the spastic gait is missed, because the normal gait cannot be broken up into stretches by successive positions. Minkowski[4] described as follows the unitary temporal character of voluntary movement, in a lecture given in Vienna:

> I have decided to go from here to the Danube to look at it in the moonlight. . . . I can measure the distance which I have to traverse, I can calculate the time it will take and which will be dependent on my speed of walking, and if I should happen to be a good physiologist I could determine as well the number of calories consumed. However, have I accounted for all the facts in this manner? Not at all. If I remain standing still halfway, have I reached half of my goal? No, because while I am going to the Danube and while I am walking for several kilometers, during which activity minutes elapse, my consciousness of the act which I am completing is stretched out over the whole like an arch. This consciousness cannot be subdivided, it is continuously present as a whole and as such it contains in each moment that which has been accomplished, that is, all the past and the future phases in a specific, indivisible temporal organization which is spread out without interruption between the moment when we have made the decision, until the fulfillment of the act.

One need not leave the description of the indivisible temporal organization of the act on the level of a metaphorical description, if one compares the temporal structure of the spastic gait with that of the normal gait, since what is closely interwoven in the normal state becomes separated in pathological states. The movements and the positions of the two legs of a person who walks downstairs are integrated in time in a very specific manner. These movements and positions are, as it were, telescoped into each other *in time*, so that the bending of the left leg while it is in a station-

ary position prepares the movement of the right leg seeking the next lower step. This temporal interpenetration of positions and movements is the basis of the unitary character of the task "walking downstairs," which is subjectively experienced as an indivisible whole. For the mechanistic approach toward the organism there are no indivisible wholes and certainly not of the macroscopic dimension of a voluntary activity. There is nothing to prevent physiological, mechanistic analysis from dissecting the movement "walking downstairs" into smaller units with the aid of coordinate system, measuring rod, and clock because, for that approach, movement is nothing but a going from position to position. For a holistic approach, the voluntary act cannot be broken up into smaller units without destroying the unitary, holistic character of the act.

From this point one can see the abnormality of the spastic gait in a new light: the patient attempts to impose the temporal structure of normal voluntary movement upon his rigid musculature, at the expense of much effort. On a horizontal surface he shuffles along fairly comfortably, his feet scarcely losing contact with the ground. He becomes more and more space-bound as he sticks more and more closely to the horizontal with the progression of his disease, since leaving this plane means the necessity of projecting the immediately following movement into the future, as the position of one leg has to be intermeshed with movement of the opposite leg. Walking on the level becomes more and more like one continuous position in which preparation for future movement is hardly necessary. Quite differently does he behave on a staircase: he experiences only a brief moment of relief, as his entire body comes to a standstill on each step; and from that resting position he forces himself down to the next lower, i.e., future, step. His rigid musculature does not allow him to strive into the future like a normal person; he is limited in his future-striving and has to break his movement up by successive positions. It requires a determined effort to impose a semblance of goal-striving tendency upon his rigid musculature, which not only freezes him in space, but also in time. Since he cannot telescope movement into position, the temporal and spatial intermeshing of movements and positions is lost and his movements become more and more a juxtaposition in time and space.

Bergson[5] has emphasized the contrast between juxtaposition and interpenetration in many of his works, e.g., where he says:

> In conclusion, let us therefore distinguish between two forms of multiplicity, two quite different conceptions of duration, two aspects of conscious life. Underneath homogeneous duration, which is an extensive [spatial] symbol of true duration, an astute psychologist disentangles a duration of which the heterogeneous moments penetrate one another; . . underneath a self which has defined states, one can uncover a self where succession implies fusion and organization.

Only a holistic approach toward the organism can deepen our understanding of this interpenetration in time which is the essence of the wholeness of the organism. The analysis and description of holistic principles are hampered by the paucity of language; therefore I have devised two terms which, I hope, will aid in the crystallization of our thinking about these highly subjective aspects of the living organism. The term "basic mental triad"[6] was coined in order to highlight the specific temporal organization of our acts which, standing on the crossroads between past and future, synthesize in the present instant our individual past with our individual future. *Pari passu* with the concept of the triad it is necessary to develop a specific time form in which our acts unfold themselves. The concept of the "precious present"[7] focuses on the temporal integration of the basic mental triad, and this modality of time should be differentiated carefully from the time form of the mechanistic natural sciences.[8] The interpenetration of the three basic mental functions in the triad and of the three basic components of time in the precious present make these concepts useful tools in defining holistic principles more fully.

The objective, mechanistic approach toward the organism studies partial functions, isolated from the total organism, thereby excluding the concept of totality from the scope of physiology. This mechanistic approach should be complemented by a subjective, holistic approach, in order to learn about the organism as a whole. Since the methods of mechanics do not apply in this subjective field, one cannot use coordinate system, measuring rod, and clock; therefore, other methods of study have to be developed.

Extrospection and Introspection

If one wants to find an answer to the question of how a living organism constitutes a whole, one has to look within himself. Looking at partial functions of the organism after the manner of mechanics will never give us insight into the totality of the organism, because this totality cannot be reconstructed from artificially, experimentally, or pathologically isolated phenomena. This very isolation does away with the organism's totality, since

phenomena which can be studied in isolation do not partake of the specific temporal organization of the whole organism. These isolated parts are apprehended by what Yakovlev[9] has called "extrospection," whereas introspection gives us knowledge about our own wholeness.

> Holism and pluralism represent two phases of the evolution of human consciousness—the consciousness of ourselves and the consciousness of the experiential world about us. . . . It is largely through this abstract, extrospective and pluralistic outlook that man has achieved what we call industrial progress. . . . But whenever man turns upon himself, the abstract mechanistic reality of the measurable world about him loses its relevance and recedes into the background of his consciousness. Man becomes re-absorbed, as it were, into the world of primordial reality. . . . And in this phase of our experience of living, every one of us is a holist by definition. . . . The resurgence of the new holistic phase . . . is no abstract, metaphysical holism so often verging on mysticism, but a pragmatic, indeed, *empirical* holism.

How can one develop an empirical holism along scientific lines? The only wholeness we know about directly is our own, private, subjective wholeness as we experience ourselves as living, acting, striving human beings. The only way we can investigate this wholeness is by introspection. The question then revolves around the problem of developing a scientific method of introspection. And this very question seems to contain an insurmountable contradiction: the data of science and its methods are objective, available to all, and, supposedly, independent of the knowing subject, whereas introspection is turned inward toward the subjective, private experience within ourselves, which is inaccessible to others.

This contradiction cannot be resolved if one holds that mechanics and mathematics are the only true sciences and that all other scientific methods should be modeled after their example, because, then, introspection is a thoroughly unscientific procedure. Mechanics and its allied sciences, such as physics, chemistry, and physiology, conceive reality as consisting of discrete bodies existing in space and in time in juxtaposition, which is the atomistic conception of reality. Some organismic phenomena, however, are not juxtaposed in time but form a whole in virtue of their interpenetration in time; therefore, holistic principles should be conceived from an entirely different, nonmechanistic, nonatomistic point of view. This is an approach toward the living organism not as "a plurality of parts, causally connected, yet distinct in their spatial juxtaposition,"[10] but as a developing, becoming whole. From this viewpoint one can elevate introspection to a scientific method of investigation.

The development of introspection comes up against a consistent trend in our entire educational system, from preschool days through university, which is bent on the eradication of an introspective attitude. For instance, the emphasis placed on mathematics constrains the student to think in terms of discrete, juxtaposed quantities applicable to objects in space. We are so used to dividing reality up into discrete objects in space that we become insensitive to our inner subjective life as it develops in time. A clearly directed effort is necessary if one wants to encourage the resurgence of this sensitivity.

Introspection is used as a method of investigation in scientific disciplines which place the emphasis on temporal rather than on spatial relationships. I am thinking in particular of history, which is the science par excellence of temporal relationships. This science describes and tries to understand human beings as they have developed and as they have acted in time as totalities. Since "development," "individual," "acting in time," are concepts foreign to the mechanistic, atomistic approach toward reality, history operates with concepts opposite to those of mechanics. From a methodological point of view, introspection must be one of the major methods of writing history, since the historian can understand the individuality, the actions, and the development of his subjects only insofar as he understands himself.

Another field in which introspection plays a major role is psychiatry. It can hardly be accidental that the methods of history and those of psychiatry have so much in common: both sciences strive to understand man as a whole human being, developing in time and striving after future goals. The psychiatrist has to be aware of the feelings and thoughts aroused within himself during therapeutic sessions, and this registration of one's internal state is, clearly, introspection. Introspection has remained on an intuitive level in psychiatry because the trend of mechanistic thinking that dominates biology has also dominated psychiatric thinking. A clearer delimitation of mechanistic against holistic principles will promote the elevation of introspection to a scientific level. Psychiatry, in particular, can profit from contemplation and critical scrutiny of its methods.

Mechanistic Methods and the Totality of the Organism

The limitation of mechanistic methods in biology consists in the totality of the organism. Many biologists have attempted to synthesize this totality with mechanistic concepts. Pavlov[11] was

a protagonist of a powerful trend in biology which attempts a theory of man in his totality on a mechanistic basis; for example, he said "when religion was attacked . . . it was the highest of all conditioned reflexes, and the one that distinguished man from beast." The reflex theory of animal and of human behavior is an application of mechanistic thinking to the problem of totality, since stimulus, central elaboration, and motor output are three discrete, successive phases, juxtaposed in time and not interpenetrating in time. I believe that one can prove through an analysis of the temporal structure of living organisms that it is impossible to synthesize the totality of the organism from elements juxtaposed in time, since the essence of this totality is interpenetration in time.

Sherrington[12] frequently alludes to the problem of the temporal integration of higher levels of animal and human behavior and points out the limitations of the reflex theory:

> Reflex behaviour is not attached to the individual's time-scale because the pure reflex is outside of "time." The sparrow that flies up the roadway as the car comes on, forecasts "time" as no purely reflex sparrow could. . . . Such consistency in sequences of situations as is shown by our dog when we call him from the road . . . lies beyond all reflex accomplishment. [And, page 291]: Now, living, so far as breathing, moving, assimilating, growing, reproducing etc., amount to life, has by natural science been accounted for. . . . They are chemistry and physics. But though living is analysable and describable by natural science, that associate of living, thought, escapes and remains refractory to natural science.

The limitations of mechanistic, natural scientific methods in biology can be defined by delimiting mechanistic against holistic principles, by showing that all scientific thinking depends on two opposite attitudes which man takes toward reality. Rickert[13] postulated, in a painstaking analysis of natural scientific and historical concept formation, two opposite trends in man's approach toward reality:

> . . . the contrast between mechanism and teleology is not inherent in objects themselves, but merely in two mutually exclusive manners of conceiving the same things: on the one hand, one works with natural scientific concepts of a most general nature, i.e., mechanistic concepts, and, on the other, with concepts of relative historical content which are referable to objects, similar to ourselves and which we therefore necessarily conceive teleologically.

In biology we know about concepts of relative historical content through introspection. Thus, the contrast of mechanism versus holism can be defined from the standpoint of the knowing subject; the resolution and synthesis of this contrast are matters of epistemology. Yet biology can profit from the realization that these two lines of thought run through all sciences.

The contrast of mechanism versus holism can briefly, though one-sidedly, be summarized as follows: understanding phenomena as mechanisms means that we look backward in time, into the past; understanding phenomena as wholes means that we look forward in time, into the future. Or, again: the contrast of mechanism versus holism is one of past-determinacy versus future-striving. The attitude of extrospection is to mechanistic principles what introspection is to holistic principles; the contrast between extrospection versus introspection is a looking at phenomena with the emphasis on their organization in *space,* versus the emphasis on their organization in *time.* Holistic principles need not be a catchall for those aspects of reality we do not yet understand from a mechanistic-atomistic point of view, but can be raised from the level of semimystical, animistic, intuitive convictions to the status of scientifically defined and practically useful concepts, through the analysis of the temporal structure of the various modalities of movement of living organisms.

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The History of Corn

PAUL WEATHERWAX

A native of Indiana and a teacher in its schools and colleges for many years, Dr. Weatherwax (Ph.D., Indiana, 1918) has pursued his studies of the morphology and phylogeny of various grasses in all parts of the Southern and Southwestern states and in several Latin-American countries. Since 1915 he has been particularly interested in the origin and anthropological relations of Indian corn.

APPARENTLY the first permanent contact of European civilization with Indian corn came less than a month after the discovery of the New World. An exploring party that Columbus had sent inland in Cuba returned on the night of November 4 and reported having seen large quantities of a grain which the Indians called *maize*. It has sometimes been thought that the Norse explorers who visited America half a century earlier had seen the plant, but those who have investigated the question thoroughly are pretty generally agreed that they did not. Even if they did see maize, there is no record of their taking it to Europe, and it had no further effect on European history at that time.

Corn in Ancient America

As the New World was explored during the sixteenth century, maize was found in cultivation by the more advanced Indian races everywhere, and all evidences indicated that they had been growing it for a long time. Numerous varieties showed wide ranges of variation and remarkable adaptation to altitude, latitude, and local conditions of soil and climate. To provide suitable cornland, swamps had been drained, deserts had been irrigated by elaborate systems of reservoirs and aqueducts, and large areas of steep mountainsides had been made arable by terracing. The fertility of the soil was being maintained by an intelligent use of fertilizers and various types of crop rotation. A great body of religious ceremony, folklore, and arts had grown up about the culture and uses of the plant. And, to know exactly when in the changing seasons corn should be planted, some races of Indians had made accurate astronomical observations and had devised the best calendars in the world.

As the exploration of the New World proceeded, questions about corn began to arise. Where did the Indians first get this remarkable cereal? What sort of plant was it when its domestication first began? How long had it been cultivated before the white man came? For four hundred years very little progress was made toward answering these questions. We do not today have entirely satisfactory answers for any of them, but we have much information of the sort from which the answers may ultimately come.

The early Spanish chroniclers who wrote about America were not trained botanists, and what they wrote about corn is confusing and often very inaccurate. At best they give hardly more than a fair superficial description of the plant and somewhat better discussions of what it meant to the Indians. The European herbalists of the same period did a little better. They published more accurate descriptions and introduced illustrations, some of which were very good; but much of what they wrote or pictured was based on distorted accounts brought back by explorers or on a few, often atypical, specimens they had seen in European gardens.

Corn in Modern Botany

An important chapter in the story opened with the discovery of *Tripsacum* and *Euchlaena*. The exact time at which these two genera came to the attention of botanists is not known, but *Tripsacum* was included in one of Linnaeus' publications in 1759. *Euchlaena* was probably known to the Indians of Mexico and Central America for centuries before the Spanish conquest, but it did not receive a scientific name until 1832. As early as 1875 it had been suggested that these plants were related to maize, but the modern idea of organic evolution was still in its infancy and their significance was not realized until later.

In the brilliant era of morphological research which came near the end of the nineteenth century and extended for a decade into the twentieth, the corn plant became a center of great interest. Its unique demonstration of xenia was recognized as

the perfect complement of double fertilization. Its extreme variability, particularly in the endosperm, the high fertility of crosses between its varieties, and the ease with which its inflorescences could be manipulated experimentally made maize one of the natural cornerstones of the science of genetics. This interest, intensified by growing economic demands, has continued to the present.

Corn Out of Asia?

Running through the herbals and the early Spanish records there is a persistent idea that maize had been known in the Old World in ancient times. America was then believed to be a part of eastern Asia, and to the writers of that day, who still looked to the classics for all truth, it seemed plausible that Eastern explorers had occasionally made contact with the plant. Even as late as the early part of the nineteenth century this idea was prevalent. The monumental work of Bonafous, published in 1836, concluded that, although maize had had a long history in ancient America, it had existed also in the Old World at the same time.

Beginning with De Candolle's classic work in 1882, however, these ancient references were evaluated more critically, and at the same time the grasses regarded as near relatives of maize became better known. The result was a shift of opinion, and, by the end of the century, the prevalent view of botanists and anthropologists was that maize originated in America and did not appear in the Eastern Hemisphere until some time after 1500.

Reconsideration of this whole question was made necessary by the discovery of *waxy* corn in China in the early years of the present century. In reporting this discovery, Collins reviewed all the evidence and concluded that maize was of American origin but that there was strong reason to believe that it had appeared in China long before the time of Columbus.

The same question has now been raised again by Stonor and Anderson. Stonor, who has visited the primitive tribes of the hill country in Assam and northern Burma, reports that they cultivate rice, Job's tears, "millets," and maize. Maize is used as a green vegetable, as a cereal, as a brewing grain, and sometimes as food for livestock. Among the varieties are also some popcorns. These tribes have no written records, but they say that they have grown corn from time immemorial; and their customs connected with it indicate that they have had it for a long time.

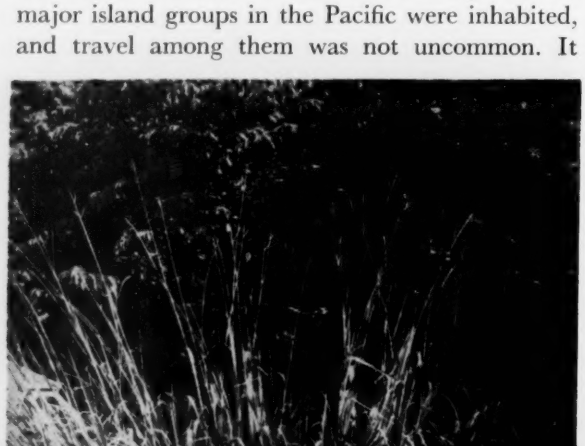
Anderson has studied materials and data collected by Stonor and has grown some of these varieties in the United States. He finds that they differ in many ways from the varieties of Mexico and the Caribbean region and show a closer resemblance to those of Bolivia and the eastern lowlands of South America. They differ also from the varieties now widely distributed in eastern China and the Philippines, which were taken there early in the sixteenth century. It is also pointed out that no trace of these varieties has been found among the more highly civilized peoples of the coastal area, through which they would have passed if they had been introduced recently. Anderson thinks that any explanation of this complex of facts must border on the fantastic, but he concludes that maize crossed the Pacific, possibly more than once, in early times and was grown in Asia as well as in America before 1492. As to where the plant originated, he urges an open-minded attitude for the present but toys with the idea of its close relationship with Job's tears (*Coix*) or with the sorghums, both of which were of Old World origin.

Anyone's reconstruction integrating these facts will depend largely upon where he places the emphasis and how he tells the story. By making adjustments in the weight of some of the items, we may arrive at a picture quite different from the one Stonor and Anderson have drawn, one which seems, in many respects, more plausible. The long history of maize in America and the presence there of the two genera most closely related to it strongly support the assumption of its American origin. On the other hand, we are not aware of a single plant fragment, artifact, illustration, or written record of undisputed pre-Columbian date to prove that the plant was in Asia before 1492. Any undocumented statement about its occurrence there in earlier times is to be regarded with skepticism until substantiated.

Near the end of the fifteenth century the Portuguese began to explore Brazil, and they soon established trade routes from there to eastern India. Maize could have been introduced into India at that time, made its way up the river valleys, and become established among the primitive hill tribes because it yielded well and was adapted to their methods of agriculture. Why it left no traces in the lowlands through which it passed is still an unanswered question, but more than one good explanation could be given. Some seventy-five years after its introduction into this area, it had migrated far enough eastward to be mentioned in the Chinese literature. These early references indicate that it came into China from the West, and the plant appeared at that time as something new and mildly exciting. This may seem a short time for a plant to have become established so far inland from the

point of introduction, but we have no substantial criterion for judging how long a thing of this kind would require. In far higher cultures today there are crop plants which have become so well established in a century that those who grow them think they have always been there. In the absence of written records, "time immemorial" may be only three or four generations.

If we consider seriously the idea that maize was in Asia before the beginning of the sixteenth century, we have still to explain how it first crossed the Pacific and in which direction. In the minds of some anthropologists the idea has been growing that there had been many significant contacts between the cultures of the two hemispheres before 1492. Leaving out of consideration the early migrations by way of Behring Strait, which have nothing directly to do with our problem, there are still numerous tantalizing suggestions that America had been host to occasional visitors from the Old World over a period of several centuries before Columbus came. Contacts with Europe, such as they were, probably had little bearing on the corn problem. Those with Africa or India across the south Atlantic would have meant much more, but direct evidences of such are lacking. All the major island groups in the Pacific were inhabited, and travel among them was not uncommon. It is not impossible that the Pacific could have been crossed, step by step, more than once in this way. As to how freely important agricultural plants passed from one hemisphere to the other, however, there is still greater diversity of opinion than Anderson's sweeping statements would indicate. The general absence of any traces of maize on the Polynesian steppingstones in pre-Columbian times is eloquent negative evidence.



Tripsacum dactyloides, Southern Indiana.

Maize and Its Relatives

The other question, that of the homeland of maize, is inseparable from a consideration of its biological origin, and that can be approached best by way of its nearest relatives.

The grass family (*Gramineae*) includes several thousand species of such diverse character that they are ordinarily separated into some fifteen to twenty or more tribes, among which the natural relationships are uncertain. Current systematic treatments of the family place maize with six or seven other genera in the tribe *Maydeae.* The only consistent character separating this tribe from the closely related *Andropogoneae* is monoecism. The *Maydeae* themselves are a diverse lot, falling into at least three distinct groups. One of these, comprising three genera, *Zea* (maize), *Euchlaena* (teosinte), and *Tripsacum,* is native to America. Another, consisting of the single genus *Coix,* was originally found in southeastern Asia and the adjacent islands, but is now widely distributed in cultivation or as a weed. The third group, made up of three or four genera little known even to botanists, occurs in about the same area as the original habitat of *Coix.*

There is little basis for speculation as to the relationships of these three groups, and they may ultimately prove to be more closely related, respectively, to separate subtribes of the *Andropogoneae* than they are to one another. Any speculation along this line based upon superficial appearances or chromosome numbers is hardly more than guesswork. It is true that when the plants are in the vegetative state, maize resembles sugar cane or the sorghums so closely that an inexperienced observer may be deceived, but there is an equally deceptive similarity between maize and many other genera. *Tripsacum* has its chromosome numbers in multiples of nine; in the other genera they appear in multiples of five. Both basic numbers are found in the *Andropogoneae.*

Among the three American genera there are, however, many other evidences of close relationship, and much of the strictly botanical approach to the problem of the origin of maize must be by

way of a comparison of them. They have been described many times and in much detail, and an exhaustive comparison is quite beyond the scope of this discussion; but it is necessary to review briefly the main similarities and differences.

The seven recognized species of *Tripsacum* have a combined range from the east central part of the United States southward to Paraguay. All the species are perennial.

The individual plant consists of one or more aerial stems arising from a system of short rootstocks. In most of the species the stem branches at every node, and all the culms may terminate in inflorescences. The latter may consist of a single spike or a dactyloid fascicle of spikes, with paired staminate spikelets in the upper part and, below these, what would seem to be single pistillate spikelets located in deep cavities arranged alternately along the axis. Beside each pistillate spikelet there is, however, a microscopic rudiment of a spikelet that has been lost.

Euchlaena grows wild from central Mexico southward to Honduras in cultivated fields or other areas not disturbed by heavy grazing. There are two species, an annual and a perennial one. The latter is known, however, from only a single locality in western Mexico; and, since the original colony has been destroyed, the species is now preserved apparently only in experimental cultures.

The perennial form is essentially much like *Tripsacum* in vegetative structure, though differing from it in habit. In the annual form, the primary axis of the seedling produces basal offshoots, and these produce others from their basal nodes, this branching continuing until, under favorable conditions, a single seedling may consist of as many as fifty to seventy-five culms. These terminate in large staminate inflorescences. They tend to branch at all the nodes, and these axillary branches branch again and again, but the internodes remain so short that the entire axillary unit is often completely enclosed in the sheath of the subtending leaf. Each ultimate branch of the axillary fascicle terminates in a pistillate spike. The spikes of the terminal, staminate panicle and those of the axillary, pistillate fascicles are, respectively, much like the corresponding parts of the inflorescence of *Tripsacum*.

The genus *Zea* includes all kinds of cultivated maize. It is an extremely variable plant, but no satisfactory way has been found to divide it taxonomically. It is known only in cultivation.

In the individual plant the branching is much more restricted than in *Tripsacum* or *Euchlaena*. The primary axis terminates in a large staminate inflorescence (the tassel), bears laterally at various

Tripsacum dactyloides. Inflorescences.

levels one or more ear-branches at as many nodes, and may produce near the ground one or more basal offshoots. In structural pattern the ear-branch is like that of the main stem, but its internodes are short, and its leaves are variously modified, forming the husks of the ear. This branch terminates in a pistillate inflorescence which produces the ear. The basal offshoots, commonly known as tillers, may take root and become more or less independent, sometimes developing into replicas of the main stem and sometimes being scarcely more than ear-branches placed low on the stem. Sometimes they remain essentially vegetative, and sometimes they do not develop at all.

The terminal tassel of maize resembles that of teosinte, but its central spike and the entire pistillate inflorescence introduce a different pattern. In each of these the pairs of spikelets are arranged in two or three rows, but more often in four or more. It will be noted that an inflorescence with *four* rows of pairs of spikelets will produce an ear with *eight* rows of grains.

This departure from the distichous pattern of structure so common in the grasses was once regarded as a unique characteristic of maize, and various bizarre interpretations of it have been proposed. But, when it was discovered that the longitu-

dinal rows were misleading and that the true rows were spiral, the magic largely disappeared, and it also became evident that similar patterns were to be found in other grasses.

A puzzling variation of this over-all picture of the maize plant is found in the variety commonly known as *tunicate,* or *pod* corn, each grain of which is covered by small husks similar in texture to those covering the entire ear. These husks are the enlarged bracts of the spikelet in which the grain is borne. They are the homologues of the chaffy scales that cover the cob of the normal ear.

The tunicate character is governed by a single dominant gene, but the plants bearing fertile tunicate ears are *heterozygous*. The homozygous tunicate plant ordinarily produces the framework of a podded ear, but this produces no grains. The pollen of this plant is nonfunctional, but the terminal tassel has various mixtures of staminate, pistillate, and perfect flowers and will produce grains if pollinated with pollen from either a normal or a heterozygous tunicate plant. Thus the tunicate character can ordinarily be perpetuated only with the aid of the normal.

Almost nothing is known of the history of pod corn. It is often grown as a curiosity or for scientific study, but the sources of these stocks are obscure. Reports of its having appeared spontaneously in cultivated varieties in recent times are yet to be verified. Since it has little economic value, it is seldom grown as a crop. It has been reported from practically all parts of the corn-growing area. Practically nothing is known about its occurrence in pre-Columbian times. There is one piece of ancient Peruvian pottery ornamented with what might be a representation of an ear of pod corn, but it might quite as well be something else.

Annual teosinte and all varieties of maize ordinarily have 20 chromosomes; perennial teosinte has 40; some kinds of *Tripsacum* have 36, but most of them have 72. Most of the Oriental *Maydeae* that have been examined have 20, but one species is reported as having 10 and one as having 40. The catalog for the *Andropogoneae* is far from complete, but multiples of nine are found in some, and five is the basic number in others. The chromosomes of the American *Maydeae* are marked by certain knobs which have been used in tracing relationships.

All varieties of maize are completely interfertile, the problem in crossing any two of them being only to bring them to flowering at the same time. Maize also crosses with annual teosinte and somewhat less readily with the perennial form. A single cross between teosinte and *Tripsacum* has been reported.

Attempts to hybridize maize and *Tripsacum* in the ordinary way have consistently resulted in failure, but Mangelsdorf and Reeves have designed a technique by means of which they have secured a small percentage of viable grains. It was later found that this hybrid could be crossed with teosinte, the result being a trigeneric hybrid. Randolph has further refined these techniques by application of embryo culture methods.

Teosinte the Wild Ancestor?

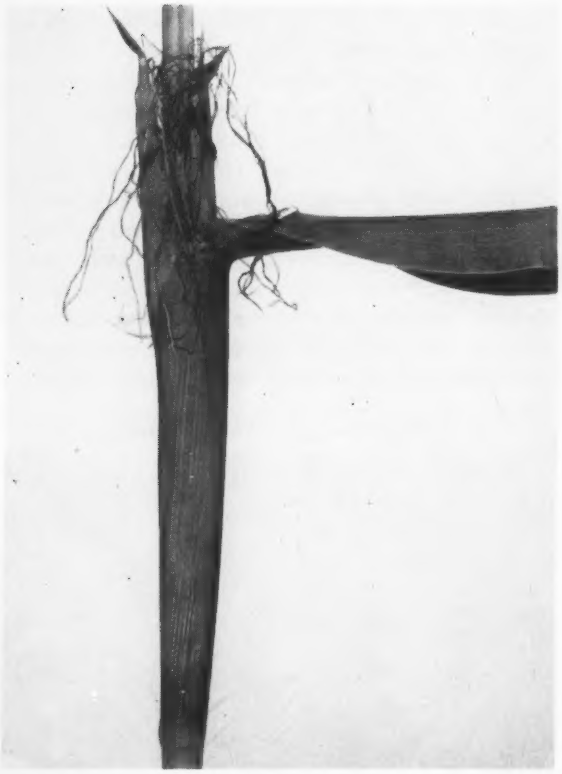
Teosinte looks so much like corn that when it is examined superficially it is easy to jump to the conclusion that it is wild corn. So convincing is this idea that many have accepted it without investigation and ignored all other considerations. A few attempts have been made to change teosinte into maize or something resembling maize by a process of selection, and at least two investigators have reported success. A critical examination of their reports, however, shows that they started with hybrids between teosinte and maize and really accomplished nothing except to sort out enough maize genes to produce the misleading result.

One serious drawback to this explanation of the origin of maize is that teosinte was of so little value to the ancient Americans that it is difficult to see what incentive there would have been for cultivating it or trying to improve it. It is a good forage plant, but the North American Indians had no fodder-eating animals before the white man came. Its seeds are so small and so securely enclosed in the hard shells that the work of preparing them for food would have far outweighed their value, unless we regard one additional fact as significant. When the fruits are heated, the grains pop like popcorn, and the edible part is thus freed from the shell. The accidental discovery of this process long ago by the Indians might have initiated the process of domestication. Except, however, for one tradition of doubtful reliability, there is no evidence that teosinte was ever used in this way.

Another objection to teosinte as the wild ancestor is that it is in many ways more highly specialized than maize, and it is difficult to think of enough fortuitous mutations occurring in close succession to set in motion the process of domestication. We may, however, be taking too narrow a view of the possibilities of mutation. Certain single-gene mutations, such as teopod, involve such extensive modifications in the entire plant that it may be well to keep in mind the possibility that a single mutation in teosinte might have been sufficient to give rise to the progenitor of maize.

We still have nothing that can be regarded as

Teosinte. Staminate inflorescence.



Teosinte. Segment of stem with axillary pistillate inflorescence.

Teosinte. Probably a single seedling plant; on an abandoned seed farm in Forida.

positive evidence that maize is a direct descendant of teosinte, and there are several good reasons for doubt that it is; but it is probably well not to exclude this possibility entirely until we have convincing evidence of some other origin.

Hybrid Origin?

For many years during the early part of this century, much of the discussion of the natural affinities of these plants centered about the idea that maize was originally a hybrid between teosinte and some other plant. This theory was born of a peculiar set of circumstances. In 1893, Harshberger published a monograph on maize, based on the assumption that a certain cornlike plant which had been introduced from Mexico was the wild corn plant. It was soon pointed out, however, that this plant was well known to Mexican botanists as a hybrid between corn and teosinte. In a later statement correcting this error, Harshberger suggested that the corn plant itself was a hybrid between teosinte and some other plant. This theory followed a wayward course for several years, the other parent of the hybrid appearing sometimes as an improved strain of teosinte, sometimes as pod corn, and sometimes as some unknown hypothetical plant; but in recent years it has receded into the background.

Pod Corn the Wild Plant?

It has always been easy to think of pod corn as wild corn, and the popular literature, at least, abounds with references to it, accompanied by the statement that the problem of the origin of corn has at last been solved. Those who are acquainted with the monstrous nature of pod corn and know that it is no more able to maintain itself in the wild state than is ordinary corn have been reluctant to accept this theory, but it has recently been raised again in a provocative form by Mangelsdorf and Reeves as a result of their success in hybridizing maize and *Tripsacum*. Their theory is that pod corn is essentially wild corn which has persisted from ancient times and that teosinte came into existence recently, possibly as late as A.D. 600, through the hybridization of maize with *Tripsacum*. It is further thought that, after the new species, teosinte, arose in this way, cultivated maize was profoundly affected by the introgression of *Tripsacum* germ plasm through crossing with this new species.

This new theory pictures the original wild pod corn as having bisexual, paniculate inflorescences terminating the main stem and the lateral branches and having bracts long enough to cover the grains. The ear-branch of modern maize arose through a shortening of the internodes of the lateral branch,

Pod corn. Ear-branch of a heterozygous plant.

the reduction of its leaf sheaths to form the husks of the ear, the suppression of the lateral branches of the panicle, and the abortion of the bracts of the spikelets.

The course followed by the abortion of the bracts of the spikelet—in other words, the loss of the tunicate character—is suggested by the discovery of a group of weak tunicate alleles. The present inability of pod corn to perpetuate itself independently is explained by the assumption that the ancient tunicate character is now superimposed upon an incompatible complex of new characters introduced by domestication.

Previous to the proposal of this theory we had been limited to Mexico or Central America as the probable homeland of maize, because it is only there that teosinte grows naturally. But, with teosinte explained away in this manner, the new theory points to Bolivia or Paraguay as the place where maize arose, because pod corn is frequently reported from that area.

This ingenious theory, which has now been before us for more than a decade, has attracted wide attention and raised many questions. It is probably time to emphasize some of its weaknesses and suggest some alternate interpretations. The first weakness is in the equivocal nature of pod corn. This variety comprises a complex of characteristics, many of

which consist of the development of parts ordinarily suppressed during ontogeny. It is easy to think of these as primitive characteristics which have never been lost by pod corn. Some of them, however, have more the appearance of monstrosities; that is, organs have developed in ways in which they never would have developed in any sort of primitive ancestor. The mechanism by which bracts, flower parts, etc., are suppressed in the ontogeny of ordinary maize is not known, but it is reasonable to think of it as having some sort of hormone basis; and it looks as if the single gene responsible for the tunicate character has a profound influence on this entire system. Some other monstrous mutations, such as teopod or corn grass, may be explainable in the same way.

Mangelsdorf's assumption that the self-sterility of pod corn is due to the modifying effects of the modern genic complex on which it is now superimposed is an interesting one, but there is very little to show that it is the right one. Monstrous forms often show some degree of sterility. The half-tunicate character looks like a more promising lead toward the original type, but, if our impression is correct, its gene does not affect other characteristics of the plant as does that for tunicate. So it may be that, as far as evolutionary significance is concerned, tunicate and half-tunicate really have little or nothing in common. In other words, if we concede all the modifications that must be made in pod corn to make it fit the requirements of wild corn, there will not be much of it left except the pods; and any theory will grant that the wild plant had some such grain covering.

The second weakness in this theory is that it does not seem very likely that maize and *Tripsacum* would ever have hybridized in the first place. The crosses that have been made have required special techniques not likely to be approached in nature, the reciprocal cross has so far proved to be impossible, and the single species of *Tripsacum* that has been crossed with maize has its normal range far away from that of teosinte, the alleged hybrid.

A third weakness of the theory lies in the uncertainty as to whether a plant species as stable and distinct as teosinte could have been produced in this way. Opinions on this point may be expected to vary until some more positive evidence of the validity of the theory is found.

The Bat Cave Corn

In the summer of 1948, an archeological excavation made in Bat Cave, in New Mexico, disclosed some remains of maize which Mangelsdorf and Smith have cited as having an important bearing on this question. Analysis of the maize material is said to show, from the lowest layer upward, a progressive increase in the average measurements of the cobs and grains, a decrease in the lengths of the bracts of the spikelets, a general increase in variability, and what is characterized as an increase in the amount of teosinte or *Tripsacum* germ plasm. From all this it is concluded that the material displays a continuous evolutionary sequence from a small-grained, tunicate or half-tunicate popcorn, in which the husks did not entirely cover the ear, upward toward the modern types.

It is obvious that every fragment of material of this kind is worth careful study as a potential source of clues to the mystery of the origin of corn, but we must confess a degree of skepticism as to the broad conclusions which have been drawn from this discovery—and certainly much skepticism about what has been stated or implied in some of the reviews and news reports. No cultural or other correlations have been cited to indicate the span of time represented in the deposit, and it seems a little naïve to assign a date of 2500 B.C. to the lowest layers simply because the formation on which they rest are at least that old.

Some of the botanical interpretations are open to question. The structures regarded as leaf sheaths in the phylogenetic process of enveloping the ear are

Pod corn. Ears of heterozygous plants.

described as having no cross-venation, a thing which would be hard to explain if they were corn leaf sheaths in any stage of evolution. The evidence of *Tripsacum* or teosinte introgression in the materials of the upper layers seems far-fetched. The illustrations shown are not very convincing as to the tunicate character of the materials at any level, and there must be something wrong with the artist's reconstruction of the primitive podded ear, in which the *individual grains*, rather than the *pairs of grains*, seem to be spirally arranged. It is possible that another examination of this same material, guided by a different hypothesis, would result in other, equally plausible conclusions.

Divergent Evolution

During the half century in which these various theories have experienced the ebb and flow of popularity, there has always been in the background the simple, conservative view that *Tripsacum*, teosinte, and maize have arisen directly from some common ancestor by ordinary divergent evolution. This theory has lacked the novelty of most of its competitors, but in many ways it fits all the facts better than any of them.

Starting with a single morphological pattern, in a plant which we can picture only hypothetically, the three genera seem to have diverged mainly by the differential suppression of various organs. In doing this they followed what seems to be the dominant evolutionary trend in this part of the grass family. Organs suppressed in phylogeny were not entirely lost but remained as rudiments, and some of these reappear in functional form from time to time, either as ontogenetic freaks or as mutations. It seems not unlikely that some stable characteristics of modern maize may have been lost and then reacquired in this way.

We picture the ancestral form as a plant with the habit of teosinte or of some of the tropical species of *Tripsacum*, with paniculate inflorescences terminating the main culm and the branches. Each inflorescence had pairs of staminate spikelets in the terminal portion and pairs of pistillate spikelets toward the base of each of its branches. The staminate spikelet was two-flowered, but the pistillate had only one functional flower and a rudiment of ananother. The lower glume of the pistillate spikelet and the adjacent rachis segment had probably not yet developed into a hard shell.

As the modern genera evolved from this ancestral form, we are not so much here concerned with the lines tending toward teosinte and *Tripsacum*. The principal trends consisted of the progressive shortening of the branches of the main culms and the sexual differentiation of the inflorescences.

In the line leading toward maize, the same general pattern was followed, but the reduction of the branches was more drastic. In the extreme case, only one or two of these remain as the ear-bearing branches. By a phylogenetic shortening of the internodes and the accompanying abortion of parts, this entire branch has been drawn into a covering of leaf sheaths—the husks of the ear—and only the terminal inflorescence of the branch remains, now reduced to the thick spike better known in its mature form as the ear of corn.

The two styles of the pistillate flower fused into a single elongated "silk" as an essential concomitant of the retreat of the pistillate inflorescence into the covering of husks. Both pistillate spikelets of each pair have been retained, and the bracts have degenerated into the chaff which covers the cob. A few varieties of maize also reach far back into their phylogenetic history and reinstate a characteristic which must have been lost soon after the panicoid grasses became separated from the rest of the family. This consists of the full development of the lower flower of the pistillate spikelet, so that the pair of spikelets now produces four grains instead of the usual two.

The two-ranked, alternate arrangement of the pairs of spikelets in the hypothetical ancestor still appears in the branches of the staminate tassel, but somewhere in the course of these events, an important innovation has appeared. The axis of the pistillate spike and that of the central spike of the tassel have become thickened, and the pairs of spikelets now appear in more than two rows, this laying the foundation for ears with six or usually more rows of grains.

Since there are no fossil or archeological remains to guide us, we find it difficult to correlate these various lines of change and picture the plant as a whole at any one time. It is conceivable, however, that there came a time when, by natural processes, it had taken on an appearance not very different from that of some relatively undeveloped varieties cultivated today. That is, it had terminal staminate panicles on a few main culms and pistillate panicles in various stages of reduction to the spicate form on numerous branches. The small ears, with eight or more rows of grains, were partly enclosed in the leaf sheaths, and the small grains were partly enclosed in the bracts of the spikelet. A plant like this would have some of the characteristics of Mangelsdorf's half-tunicate types, but it would not be handicapped by the monstrous nature of pod corn.

Even though this hypothetical plant was fertile, it was poorly fitted to survive in nature, and its evolution was proceeding in a direction which was making matters worse. The axis of the ear had lost its ability to break up into pieces, and there was no natural way by which the grains could be detached from the cob, escape from the covering of husks, and be dispersed. If the entire ear fell to the ground, the seedlings grew in a compact cluster, and none had a good chance to survive. If an occasional grain did become detached from the ear, it fell an easy prey to its natural enemies. If this plant were a perennial, however, it might persist for a long time after it had begun to lose ground as a natural species. And it is not unreasonable to assume that it was a perennial; all species of *Tripsacum*, as well as one of teosinte, are perennial.

The Beginning of Domestication

At about this time the Indian appeared on the scene. By what steps of accident or trial and error he learned to cultivate maize will probably never be known. But some of the very characteristics which mitigated against its success in nature gave it special values as an agricultural plant, and domestication insured its survival.

The place where the plant grew wild and where maize agriculture first began are still unknown, but this theory points to the Mexican plateau and the highlands of Central America, the area where both *Tripsacum* and teosinte now grow wild. The Aztec and Maya civilizations, which were based on maize agriculture, arose in this area.

To ask what caused these three genera to follow divergent lines rather than to lose their identities by repeated hybridization with one another is to raise the entire question of the mechanism of speciation. Very early there must have arisen some sort of genetic incompatibility between *Tripsacum* and the precursor of the other two genera. This is reflected in the basic difference in their chromosome numbers and more so in their present inability to hybridize. The later separation of maize and teosinte must have come from some physical barrier, because they have remained completely interfertile. Previous to its adoption by the Indian, a small population of the pro-maize plant may have been fighting a losing battle in some canyon or ravine, while the much better adapted teosinte flourished over wider areas. Domestication produced a profound change in this picture. With the help of man, maize now moved out into more favorable localities. This brought it into the range of teosinte, and hybridization began. The Indian soon learned that the hybrids were of no use to him, and he tended to eliminate them from his fields along with teosinte and other weeds. And so, with the one species preserved by nature and the other by man, and the hybrids finding no friend in either nature or man, the two species continued to inhabit the same area with a minimum of permanent hybridization. Some exchanges of germ

Pod corn. Staminate tassel of a homozygous plant.

plasm did occur from time to time, but teosinte continued to be predominantly teosinte and maize to be maize.

The story told by the chromosome knobs fits this theory. Most species of *Tripsacum* have numerous knobs. In teosinte the number is smaller, and in maize it is still smaller, with some varieties having none. The average number of knobs in maize varieties decreases with distance north or south from Central America—that is, with distance from the area where contamination with teosinte is most likely to occur. We have so far no explanation of where the knobs came from in the first place or of why maize seems originally to have had few or none.

A New Chapter

Another chapter in the history of corn is just now in the making, and, unless steps are soon taken to turn it in a new direction, the ending may be something of a tragedy. The entire complex of maize varieties now grown in various parts of the world

comprises a vast pool of characteristics, and basically of genes, from which the individual corn plants of the future will be built. As long as selection in open-pollinated lines was the only method of corn breeding, the chances of actually losing any specific gene were not very great. But in developing the inbred lines from which hybrid corn is produced, we ruthlessly eliminate any gene which, for the moment, does not fit our purpose. Some of these might have economic values in some other setting, and all of them are of such biological interest that none should be lost. So far the loss has not been great. In modern agriculture there is still enough open-pollinated seed produced to insure the preservation of practically all these variations; and primitive Indian races are still carrying along a great wealth of unexplored genetic material of corn. As the economic advantages of hybrid corn become better known, however, and as undeveloped areas are opened by better means of travel, much of this primitive material will be discarded in favor of more useful stocks. It is not too soon for large research organizations to be giving serious thought to measures for conserving this great heritage.

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Their [scientists'] business is not with the possible, but the actual—not with a world which might be, but with a world that is. They have but one desire —to know the truth. They have but one fear—to believe a lie.

From an address by John Tyndall in Liverpool, September 16, 1870

SCIENCE ON THE MARCH

SHEET MATERIALS FOR WRAPPING FROZEN FOODS*

THERE is much evidence in the literature to indicate that wrapping and packaging materials have an important influence on the retention of quality of frozen foods.[1,2,3,4] The basic reasons for the protective value of the more effective materials are not so well understood, however.

Throckmorton[5] believed that the most universal problem in packaging foods is to prevent the transfer of gases and vapors through the walls of the container. Since that time (1942) the permeability of many sheet materials to gases and moisture-vapor has been determined at above-freezing temperatures and various relative humidities, but no comparable data are available for low-temperature storage conditions.

A major problem in the storage of frozen meats is to retard the development of rancidity of the fats. Efforts to stabilize fats usually are concerned with the prevention of changes caused by enzyme action and by atmospheric oxidation.[6] The term "oxidative rancidity" is used to denote the deterioration in flavor and odor that occurs when atmospheric oxygen reacts with the triglycerides or other components of natural fats.

Excessive weight losses (5 per cent or more) resulting from the use of packaging materials having relatively high rates of moisture-vapor transmission have been cited as a major cause of quality deterioration. Nevertheless, it is readily demonstrated that excessive loss of weight, per se, is not necessarily correlated with loss of palatability. It has been found that the packing of adequately processed green beans in stockinette only,[7] and the packing of ground beef in hermetically sealed containers with an inert desiccant,[8] resulted in little loss of flavor during periods of storage in which the weight losses exceeded 5 per cent.

Effect of oxygen. In one experiment,[8] metal containers were filled to about one-third capacity with ground beef and stored at 0° F. Atmospheres of low-, medium-, and high-oxygen content under both normal and low relative humidities were maintained in the containers during storage periods up to 7 months. There was a significant decrease in palatability with an increasing oxygen content of the atmosphere surrounding the meat. The data indicated little difference in flavor between lots having low weight losses and those having high weight losses resulting from excessive desiccation.

On the other hand, weight losses in foods sold by the pound are very important from the commercial viewpoint. Furthermore, excessive weight losses frequently are accompanied by a deterioration in appearance of the product, such as the so-called freezer-burn of meat (Figs. 1, 2).

It seems apparent that wrapping and packaging materials for frozen foods should have low rates of transmission for both oxygen and moisture-vapor at temperatures of 0° F. or lower. These values are not critical for short storage periods because loss of quality resulting from poor packaging seldom is apparent during the first few weeks of storage.

The use of antioxidants impregnated into cardboard and dispersed in the coatings of cardboard and paper has been suggested as a method of retarding rancidity development in packaged fat-containing foods, and at least one wrapping material of this type has appeared on the market. An aqueous solution of ascorbic acid also has been used for fish fillets as a dip prior to packaging.

Moldability. Sheet or bag materials of good protective value should be pliable enough to make a close, tight wrap, because the amount of air space inside a package in relation to the volume of food and the surface area exposed should be held to a minimum. A completely moisture-vapor proof seal cannot protect food from loss of moisture if large cavities exist within the package. In such a situation moisture from the food is deposited as ice crystals inside the package.[9] Temperature fluctuation is the principal cause of transfer of moisture from the food to the surrounding air space.

Ice crystals do not build up inside a package when the packaging material has a relatively high rate of moisture-vapor transmission.[9] Under such conditions, and when the permeability to oxygen is high, it is probable that air pockets inside the package are of little added significance.

Other desirable qualities. A wrapping material for frozen foods should have other qualities in addition to those previously described. The material should be greaseproof; odorless, especially when damp; and should possess high wet strength so that meat juices or other liquids will not cause it to soften and break. It must also be strong enough

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to resist tearing and puncturing in wrapping and handling; easy to mark for identification and date of packing; and not become brittle or crack at low temperatures. A sheet material should have good "stripping" quality so that it will not adhere to the meat when the package is unwrapped. A Mullen test of not less than 32 pounds is considered the minimum bursting strength desirable for waxed paper and laminated sheets. This test measures the pressure necessary to rupture a circle of sheet material having an area of one square inch. For locker plant use, a sheet material should be adapted for use on a paper cutter.

Sanitary standards. Investigations have shown that, in general, paper and paperboard products made for food packaging meet high standards of sanitary quality in manufacturing processes. The undesirable practice of retailing frozen food containers from bulk stock has largely been discontinued in favor of factory-packaged units for retail distribution.

Storage of wrapping materials. Careful attention should be given to the recommendations of manufacturers concerning the proper storage conditions for the various packaging materials. For example, waxed papers may stick as a result of high-temperature storage. They should be stored in a cool place, if possible not over 70° F. The optimum storage condition for cellophane is 65°–75° F. and 35–50 per cent relative humidity for rolls, or 50–55 per cent for bags. Pliofilm stores satisfactorily under normal room conditions. Aluminum foil should be kept in a dry place, and care must be taken to avoid damage to the ends of rolls by dropping or careless handling. Some difficulties may be encountered in the use of materials that have been stored improperly.

TYPES OF WRAPPING MATERIALS

Sheet materials are available in four distinct types; films, laminated or plastic-coated sheets, foils, and waxed papers. The waxed papers, as a group, provide less effective protection to the food than the other three types of sheet materials.

A survey[10] made among 10,715 locker plants during June 1948, showed several usages of wrapping materials (Table 1). Many plants offer more than one type of wrap.

Transparent Films

Cellophane. Cellophane is a nonplastic film of regenerated cellulose. Cellulose alone has little protective value for frozen foods unless coated. Of the many types of moistureproof cellophane, very few are recommended for wrapping moist foods

FIG. 1. Showing undesirable freezer burn resulting from use of a poor wrapping material. Storage for 11 months at 0° F.

such as meat. Dupont cellophane MSAT 83 or 87 or Sylvania cellophane MSBF-3 should be used for moist foods. Unfortunately, the wrong types of cellophane are frequently sold for freezer wrappings. Although such types often are labeled "made for frozen foods," they may be intended for wrapping and freezing dry products rather than moist meat. The MST-53, MSF-1, and MSF-3 types of cellophane are suitable for wrapping dry or prefrozen foods, but the protective coating is not water-repellent and is likely to loosen in contact with moist foods. Gauges commonly used in frozen food packaging are No. 300 (.0009") and No. 450 (.0013"). No. 300 cellophane used as a meat wrap usually requires an outer wrap of stockinette or paper to protect it from breakage in locker plant handling. No. 450 cellophane often may be used without an overwrap. The proper types of cellophane are effective barriers to oxygen and moisture-vapor. A special type of standard paper cutter is used for cellophane.

Cellophane also is available as a "double-wound" locker wrap, comprising a cellophane inner wrap and waxed locker paper wound together on the same roll.

Pliofilm is a transparent film of rubber hydrochloride. The FF type is recommended for frozen foods. Gauges No. 120 (.0012") and No. 140 (.0014") are commonly used, although for some applications a lighter gauge (Nos. 75 or 100) may be used. This film usually requires an outer wrap to protect it from breakage in locker plant handling. Pliofilm is an effective barrier to oxygen and moisture-vapor. These qualities are inherent in the film. It is very pliable and has high tensile strength. The stretched film will shrink if dipped momentarily in water at approximately 180° F. If desired, Pliofilm may be washed in hot water for reuse.

TABLE 1

Type of Wrapping Used	Number of Plants	Percentage
Waxed locker paper	7,008	65.4
Cellophane	2,250	21.0
Laminated glassine	2,111	19.7
Aluminum foil	1,714	16.0
Double-wound cellophane	1,211	11.3
Laminated cellophane	568	5.3
Thermoplastic wax dip	557	5.2
Laminated aluminum foil	396	3.7
Pliofilm	396	3.7

Saran is a transparent film of polyvinylidene chloride. It has a high resistance to tear, but when a tear has started the resistance is lowered. Saran No. 517 is the recommended type. This film has a strong tendency to "cling," making it difficult to handle, but new types are being developed to avoid this problem. Saran is an effective barrier to oxygen and moisture-vapor.

Polyethylene is a transparent film of polymerized ethylene. Ethylene, a gas obtained from petroleum, is polymerized at high pressures and elevated temperatures to form polythene, from which the film is made. Polyethylene is the lightest and most inert of the plastic films suitable for frozen food packaging. It is durable and tough at both normal and low temperatures, and possesses a good degree of transparency. Polyethylene does not soften until heated to about 212° F., so it may be washed in water as hot as the hands can stand. This film does not tear readily, so it is unsuitable for use in sheet form on a standard paper cutter. It is available in sheet, tube, and bag form.

Poylethylene is one of the newest plastics. It was developed in England and first introduced into the United States in 1943. It is sold under a variety of trade names such as Howard-Seal, Pearlon, Shellene, Tralon, and Visqueen. Polyethylene is an effective barrier to moisture-vapor, but it is not quite equal to some of the other frozen food films as an oxygen barrier.

Aluminum Foil

Aluminum foil is sheet aluminum less than 0.006″ in thickness. It is very moldable, permitting a snug wrap for irregular objects such as poultry and fish. Foil is a very good conductor of heat, so that foods freeze faster in foil than when wrapped in locker paper. It may be used with the shiny surface on the inside or outside of the package, but the dull side is preferred on the outside for ease of marking. Special inks are available that mark foil quite satisfactorily.

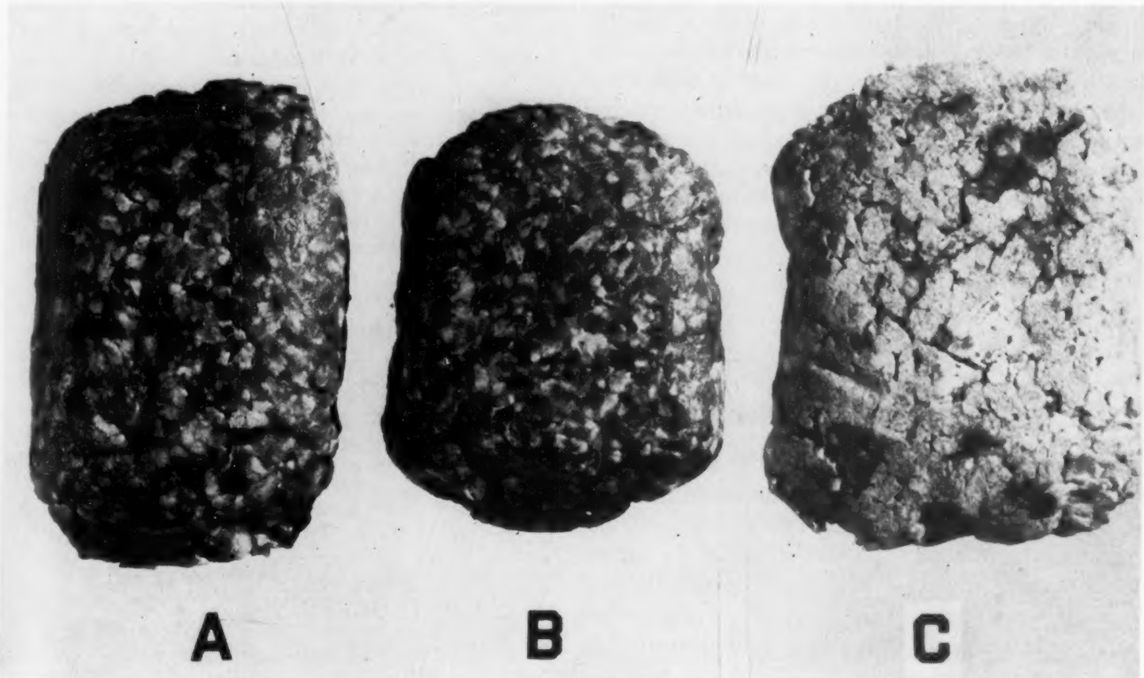

FIG. 2. Fluctuating temperatures increase amount of desiccation when poor wrapping materials are used. Ground beef samples *A* and *B* were wrapped in good materials and show little visible desiccation after storage at temperatures fluctuating from 0 to −20° F. Sample *C*, wrapped in a poor material and stored under the same conditions, shows severe freezer burn.

Foil may be used on a standard paper cutter having teeth on the cutter bar. Plain foil lighter than 0.001″ is not desirable because of pinholing and poor stripping quality. The recommended thickness is 0.0015″ in widths of less than 24 inches, or 0.002″ in 24-inch widths. Aluminum foil of suitable gauge is an effective barrier to oxygen and moisture-vapor, and it retains its strength and flexibility at extremely low temperatures.

Meats and poultry may be oven-roasted after partial or complete thawing while still wrapped in foil, resulting in considerably less shrinkage than if the meat is cooked uncovered.

Aluminum occurs naturally in plant and animal tissues, and its use as a wrapping material does not affect the wholesomeness of food in any way. Neither does it accelerate the loss of vitamins during cooking.

Aluminum and nickel were the only metals tested by Ziels and Schmidt[11] that were found to be absolutely free of any pro-oxidant effect on fat. Bryan[12] reports that four generations of rats were fed on foods which were not only packed in aluminum but which also had relatively large amounts of the metal intermixed. Growth and fertility of the rats continued entirely normal, with the aluminum completely excreted.

Laminated and Coated Sheets

Many types of laminated sheets are available for wrapping frozen foods, comprising two sheet materials laminated together by flexible adhesives. They include cellophane to paper, aluminum foil to paper, glassine to paper, glassine to aluminum foil, and others. Glassine is made by partial gelatinization of wood fibers in prolonged beating previous to the formation of the sheet of paper. In general, laminated sheets are effective barriers to oxygen and moisture-vapor. When paper is used as one of the sheet materials, the paper side is used on the outside of the package. One of the latest developments is a sheet made of polyethylene coated on paper, tests of which are now in progress.

Waxed Locker Papers

Tests of foods stored at 0° F. indicate that most, if not all, waxed locker papers now in general use have only a moderate protective value for frozen foods, except for relatively short storage periods. A single wrap of one of the more effective materials will give better protection than a double wrap of an ordinary waxed locker paper. Waxed locker papers of 40–48-pound weight are most often used, this being the weight of 480 or 500 sheets each 24 × 36 inches.

WRAPPING COSTS

Locker plants. The cost of the various sheet materials is now so competitive that practically all of them fall within a rather narrow range in terms of cost per pound of meat wrapped. Under average locker plant operation this cost is approximately 50–70 cents per 100 pounds of meat, hook weight. These costs exclude a single wrap of waxed locker paper, which is not recognized as an effective wrap.

The selection of a wrapping material, on a cost basis, rests largely on the differences in labor costs involved and on necessary investment in equipment. No published data are available on these cost factors with respect to the different types of wrapping materials.

Home packaging. The cost of wrapping and freezing meat at home is higher than is generally recognized. Wrapping materials purchased in retail rolls will cost about $1.40–$1.85 per 100 pounds of meat wrapped. When the freezing cost is added (about 11 K.W.H.), the total cost is not much lower than the price charged by many locker plants for cutting, grinding, wrapping and freezing the meat, and marking the packages.

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BOOK REVIEWS

MICRONESIA

Majuro—A Village in the Marshall Islands. Alexander Spoehr. 266 pp. Illus. $3.50. Chicago Natural History Museum. 1949.

THIS account of village life in the Marshall Islands brings credit to anthropology, to the organizations that combined to support Dr. Spoehr's research, and to the people of Majuro. With reporting such as this on the life and culture of Micronesian natives, the United States should be able to administer more effectively than otherwise the former mandated islands. And students of social life will find this study an excellent monograph on Marshallese culture and social organization.

After prefacing his work with geographical, demographic, and historical data, Dr. Spoehr turns rapidly to a discussion of Majuro village proper. This community of nearly nine hundred inhabitants forms the basic subject matter of his report. Aided by excellent photographs, he sketches the physical setting in which these people live and describes their appearance, way of life, and the structure of their social organization. The people of Majuro are divided into two major classes: commoners and nobility. Although membership in the two classes is hereditary, following the maternal line, the two classes are not at present endogamous and do not form rigid castes. This social distinction is currently in process of disintegration, and many changes in social life are related to the recent blurring of class distinctions. This is significant from the point of view of American administrative policy, for the tendency has been to capitalize upon the class structure and to deal with the natives through traditional chieftains.

Of particular interest is the attention paid by the author to factual evidence concerning cultural change. This material, as is the remainder of the volume, is organized about what might be termed the social structure of the village. There are introduced institutions: the church, the stores, the dispensary, and the school. These institutions are becoming a part of the social life and act as integrating factors helping to maintain the unity of village life. They are forming bridges between old ways and the new introduced from outside, thus helping the natives to adjust to the shock of exposure to an alien culture.

This review should not close without reference to the excellent figures representing household compositions. The charts which show males and females, their relationship and generation, all by means of lifelike figures instead of the conventional biological symbols, deserve special commendation.

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GEOMETRICAL OPTICS

Physiology of the Eye. Vol. 1. *Optics.* Arthur Linksz. xii + 334 pp. Illus. $7.50. Grune and Stratton. New York. 1950.

IN APPROACHING a book on some phase of physics written by a nonphysicist for the consumption of the nonphysics student, the professional physicist is apt to adopt a highly critical and somewhat condescending attitude, and he is prepared to pick out errors by the score. One does not have to read far in this book, however, to find that Dr. Linksz has written a textbook on geometrical optics which may be read with benefit by most teachers of physics. Although this elementary textbook presents no new material, it is so delightfully written, and the old ideas are so refreshingly presented, that reading it is a pleasure. It possesses an essaylike quality and is free of the formal stiffness that makes the reading of most textbooks a chore. Written as it is, in an informal style, as though the author were lecturing, the emphasis is less on mathematical rigor than it is on the meaning of the broad underlying physical principles. In spite of this, the material is presented in its essential correctness.

The book is divided into three parts, the first of which deals with physical optics, the second with geometrical optics, and the third with the image-forming properties of the eye.

Although the section on physical optics covers only seventy-seven pages, the author manages to discuss in a leisurely, unforced fashion the various concepts of light that have been presented to the world from the time of the Greek natural scientist Galen to the present time. Included in this material is an excellent discussion of the classical wave versus corpuscular theories. Refraction, interference, diffraction, and polarization are taken up in that order and discussed nonmathematically with the aid of Huygens' principle. This section concludes with a simple but adequate discussion of the quantum theory of light.

The major portion of the book (pages 70–270) is devoted to geometrical optics. The subject matter is presented from the point of view of the ideal theory of optical systems as developed by Gauss so that the student has all the necessary formulae developed for the paraxial region of a lens system. Starting with an excellent discussion of the action of a plane mirror on a ray of light, the author discusses the refraction properties of a single spherical surface, and then derives the equations for the principal planes and the cardinal points of a thick lens. There are two criticisms to be leveled at this section of the book. The theory of stops is not adequately presented, although use of it is made in the discussion of the aberrations of lens systems and in the

discussion of the prismatic effects of lenses. In the discussion of thick lens systems, it is assumed throughout that the lens is always immersed in a medium which has the same index of refraction in front of the lens and behind the lens—namely, air. This is often not the case, so that the posterior and anterior focal lengths will be different. This would seem to apply particularly to the system of the eye. Aside from these minor defects, this part of the book is very well written. Two features are included here which are not ordinarily found in the standard textbook. These are a fairly detailed discussion of prismatic systems and a section dealing with the properties of cylindrical lenses.

In the last forty pages of the book Dr. Linksz develops the elementary theory of the formation of images by the eye. This material is presented almost entirely from the optical point of view, since, in the two volumes to follow, the physiological and biochemical properties of the eye will be treated. The well-known refractive errors of the eye are neatly discussed and analyzed in terms of the paraxial lens formulae.

One cannot leave this book without saying something about the general format and the illustrations. The publishers have done an excellent job in the layout of the book, and the drawings that Dr. Linksz has used are so good that they could almost serve as a text by themselves.

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A REVIEW OF SCIENTIFIC INSTRUMENTS

Some Early Tools of American Science. I. Bernard Cohen. xxi + 201 pp. $4.75. Illus. Harvard University Press. Cambridge. 1950.

Cohen has a warm sense of admiration for the pioneers of American science. By tracing the beginnings at Harvard of each of the major branches of science—physics, astronomy, chemistry, biology, geology—he provides a measure of the quantity, variety, and quality of the interest in science and the place of scientific activity in the community during the colonial and federal periods. He emphatically dispels the notion that the American colonial clergy or the colleges they dominated were hostile or indifferent to natural science.

Dr. Cohen's book is in part an illustrated catalogue of an exhibition of old scientific instruments and mineralogical and biological specimens held in the Edward Mallinkrodt Chemical Laboratory in February 1949. The instruments are given meaning by brief sketches of the professors and lecturers who used the apparatus, and there is a good reconstruction of the nature of instruction offered to students in the sciences. The descriptions and accounts are all carefully ascribed to original sources.

Quite as interesting as the professors were some of Harvard's benefactors: Thomas Hollis of London, who endowed both the Hollis Professorship of Divinity and (in 1727) the Hollis Professorship of Mathematics and Natural Philosophy; Benjamin Franklin, who was generous with gifts and with advice on which instruments to purchase; and Joseph Mico, who served the college as agent in Great Britain for more than forty years without taking any commissions.

In each department of science, Cohen has limited the discussion to the founding period: the eighteenth century for astronomy and natural philosophy; and for chemistry, natural history, and mineralogy the closing years of the eighteenth century and the first quarter or so of the nineteenth. The scientific instruments that were used in that early period Cohen has shown to be the "tangible memorial to the largeness of the intellectual horizon—which included science—that characterized our academic forefathers."

In its emphasis on relating the state of scientific culture to the whole of American education and culture this book reflects the painstaking evaluations and buoyant presentation that have been commended in Dr. Cohen's own classes in general science at Harvard.

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INDICTMENT

Disaster Through Air Power. Marshall Andrews. xiv + 143 pp. $2.00. Rinehart. New York. 1950.

Marshall Andrews, of the Washington *Post,* has written an angry and searching indictment of the present and wartime United States Air Force Policy. His thesis, that the doctrine of strategic air power as proposed by the Air Force is deluding the United States into a position that will become increasingly dangerous from the viewpoint of national security, has recently been the basis of the major controversy in the Department of Defense. In addition, Mr. Andrews makes the claim that the Air Force, because of its dependence on strategic air power, is neglecting to a dangerous degree the other components of air power, tactical air power and the air defenses of this country being the major sore points.

Unfortunately, in his anger Mr. Andrews adds very little that is new to this important discussion and restates several erroneous arguments. For example, this reviewer believes that including Lieutenant General Quesada among the opponents of tactical air power is a mistake, since Quesada's policy has been quite consistent in recent years in support of improved tactics, weapons, and organizations for close support of ground forces.

The book does serve one very real purpose. It illuminates the confusion that exists at important governmental levels regarding our strategic objectives. Understandably it is this confusion that has caused the main split between the services over the problems of unification of the military establishment. The external evidence of this serious and important conflict is the recurring dispute over the details of the weapons and their control, which appears in the press as differences of opinion between the Navy and the Air Force. Mr.

Andrews presents some fine illustrations of this confusion as it exists at the Congressional level.

It is the opinion of this reviewer that Mr. Andrews might have made a more significant contribution to the difficult questions relating to national security by retaining a more objective point of view.

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SCIENCE AS A WAY OF LIFE

Science and Civilization. Robert C. Stauffer, Ed. xiii + 212 pp. $2.50. University of Wisconsin Press. Madison. 1949.

AMONG the great dilemmas of our age is the recognition that although we can't get along without science we don't know quite how to live with it. We like the increased power over nature that science has brought us, yet we cannot help feeling anxious in the thought that civilization has so far not invented preventives against the possibility that man, too, may become indistinguishable from nature. Power has become a giant, but judgment of its use has remained a baby.

It is for this reason, then, that we should all be thankful for any well-meaning attempt to consider the relations between the giant and the baby. How, for example, did the one grow so quickly and so large while the other has barely begun to walk? How is it that this same puny baby has been able to make such a mighty toy? How may the baby be entrusted to play with the toy without destroying himself? What principles can we learn from the "growth genes" of this giant of giants so that we may create a similar mutation in the baby—or rather in its future offspring? Thus, the History of Science group at the University of Wisconsin under the chairmanship of Robert C. Stauffer is to be warmly congratulated for having chosen to celebrate the centennial of the university by inviting a group of eight scholars representing various disciplines to hold a symposium to "offer their own special insights into the problem of the relation between science and civilization."

Noble ends, however, sometimes become vague or confused, especially when the problems toward which goals are to be mapped out are themselves not clearly defined. We must know where the fire is and what kind it is before we can figure out what kind of extinguishers we shall use and how we shall get them to the fire. It is perhaps because of an inadequate description—I am almost inclined to say no description—of the exact or even the approximate nature of the problem that the papers in this book seem to have very little bearing upon it and, accordingly, can give us no lead to the goal. It is not surprising, therefore, that the participants seem to be talking in all directions, blissfully ignorant of the over-all purpose of the symposium—since the purpose is hardly hinted at. Perhaps, too, because of this unconnectedness, no attempt has been made by the editor to pull the papers together.

Of the eight papers, three were written by philosophers, and one each, respectively, by a biologist, chemist, historian, physicist, and sociologist. Thus, although the great advances have taken place in the biological and physical sciences, from which we urgently need all the insights on rapid growth that we can get, only three discussions are offered from this area.

Richard P. McKeon's paper, "Aristotle and the Origins of Science in the West," urges us to reconsider our views of Aristotle, especially if we have adopted anti-Aristotelian viewpoints in our scientific attitudes. The thesis presented is that Aristotle has been sadly overlooked in his contributions to the problems of "process" and "change" and that his was not solely an interest in classification. Various authorities are cited to bolster this viewpoint, but contrary or contradictory interpretations are almost entirely neglected.

Lynn Thorndike's paper, "Some Unfamiliar Aspects of Medieval Science," really sets forth some very unfamiliar erudition of the period and comes to the conclusion that the Latin Sages of that age should not be neglected in favor of the Arabs as the middlemen between the Greek and the modern periods.

The paper by Max Black, "The Definition of Scientific Method," and the one by Ernest Nagel, "The Meaning of Reduction in the Natural Sciences," are both full of insight, and deserve to be studied by all scientists interested in these problems—and, perhaps more so, by those who are unaware of or uninterested in them. Black's enthusiastic anti-Aristotelian, pro-logico-empiricist bias might well serve as a balance to McKeon's dogmatic pro-Aristotelian bias. Both are biased but both seem to think they are not. Nagel's paper and that of Owsei Temkin, "Metaphors of Human Biology," are quite in the same vein, except that Nagel speaks of "reduction" as an abstract concept to cover all interscience relations, and Temkin's efforts are directed to a few examples, such as "organism-organ," "macrocosm-microcosm," as they have been used—and misused—in biology and social science.

William F. Ogburn's interestingly written paper, "Science and Society," tells us in twelve meaningful pages what the social sciences know and do not know, what, theoretically, they can be expected to know and not to know, how they contribute to society and are in turn affected by it. He warns us in conclusion "not to expect too much . . . nor must we expect anything too soon."

Philip E. LeCorbeiller's "Physics as a Cultural Force" and Farrington Daniels' "Science as a Social Influence," the only two papers stemming from the physical science orientation, are, with the exception of Ogburn's paper, perhaps the most clearly presented and bear to a larger extent than the other papers on the relation between the responsibility of the physical scientist to society and society's debt to the physical scientist. But, even here, we are merely presented for the most part with well-worn platitudes.

Never before have I read a book comprised of such a disconnected, although interesting and important,

series of papers, each supposedly dealing with the same over-all problem; yet only two, or three at the most, have any direct relevance to it. Perhaps, too, these might seem more relevant if more of the authors had taken greater pains to make themselves intelligible.

In conclusion, in fairness to the committee sponsoring this symposium, we should agree with the chairman and editor, Professor Stauffer, that "this volume is to be regarded as one contribution to a subject which merits continual and extensive cooperative study." Let us hope that henceforth the "subject" is better defined.

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PERSONNEL PSYCHOLOGY

Making Work Human. Glen U. Cleeton. 326 pp. $3.75. Antioch Press. Yellow Springs, Ohio. 1949.

THE reviewer picked up this book with mixed feelings; having read it, his feelings are still mixed. The initial attitude was based upon an apprehension (engendered by the title) that this would be another in the long list of semiscientific expressions of opinion, coupled with a wish for a scientifically accurate document on personnel psychology addressed specifically to management. The present attitude is based on the belief that the book has elements of both.

Making Work Human is essentially a textbook on industrial psychology written primarily for management rather than for the student. There is need for a book which is founded on research results, but which does not present the ofttimes frightening statistical minutiae upon which the results are based. Many executives have neither the time, the background, nor the inclination critically to appraise research in the area of human relations. This places a serious responsibility upon the scientist writing for management. Cleeton has, for the most part, accepted this responsibility and discharged it well.

"The primary thesis of the book is that work can be made fully as satisfying as leisure-time activities." This thesis is developed through a consideration of many facets of human relations, ranging from basic personal needs to the community responsibilities of industry. A key concept is that "production gained at the cost of employee dissatisfaction and ill will results in industrial strife and conflict." Although this concept does seem to be gaining wider acceptance in management circles, repeated emphasis is still in order.

The chapters vary in quality. Those on selection (V), training (VII), and supervision (X) are very well presented and backed up with a wealth of research experience. The final chapter, entitled Research and Judgment in Work Relations, is excellent. Other chapters contain a number of gratuitous opinions of the author on education, aid to Europe, social legislation, and taxes. For example, the reviewer felt a bit uncomfortable upon reading that, as a Federal employee, he is one of "a horde of unknown dependents" supported by the taxes of the *working* man.

Considered in its entirety and in the light of its intended audience, the virtues of the book far outweigh what this reviewer, at least, considers to be its shortcomings. It is a penetrating and thoughtful analysis of the psychological factors in industrial conflict. Perhaps more important to the executive, helpful suggestions are presented upon which positive action can be based.

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SCIENCE IN A NUTSHELL

A New Survey of Science. Walter Shepherd. 512 pp. Illus. $4.75. Harcourt, Brace. New York. 1950.

THIS is a revised edition of an earlier book by the same author, *Science Marches On.* Like the former volume, it attempts to encompass the whole of nonapplied science in a multifaceted historical presentation. Shepherd is to be highly complimented on the balance maintained throughout. As a summary in less than 500 pages, with 16 pages of index, the author does for science what H. G. Wells accomplished in his *Outline of History.* A formidable number of people are mentioned by name, date, and influence on the stream of development. This makes the book most valuable for reference purposes. The narration is sufficiently skillful, however, that the reader does not bog down among the names of the great. The reviewers wonder, on the other hand, whether the facts and events do not follow one another so rapidly as to make the going hard for the nonscientific user of the volume. So much material is introduced, some of it relevant only in the historical sense, that the gain in understanding interrelationships may be closely proportional to the breadth of scientific education already received and digested by the person following Shepherd's account. Those with an appreciation for science will find the treatment stimulating, though they may not agree with the author in his final chapter, Where is Science Going?

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CORRESPONDENCE

HE EGG AND HENRY WARD BEECHER

In the course of his devoted article "Reminiscences Professor Osborn" in the May 1950 Scientific onthly, Dr. Robert Cushman Murphy indulges in the vorite American pastime of quoting limericks and ves us that "time-honored" one about the grateful llinaceous domestic that paid so handsomely in return r the blandishments of a certain member of the neteenth-century clergy. Now limericks are a sort of lk art, and one is accustomed to hearing widely var-nt readings of the same example; but I had never ard before this version of Dr. Murphy's:

> To a hen said Henry Ward Beecher,
> "You are surely a wonderful creature!"
> The hen, just for that,
> Laid an egg in his hat,
> And thus did the hen reward Beecher.

Technically this version, departing as it does from the apaestic pattern and harboring some of the *bêtes noires* f the limerick writer, leaves much to be desired. urthermore, it omits reference to the Reverend Mr. eecher's occupation, without which the full implica-ions of the limerick are not apparent. He was not just n ordinary chicken fancier. The usual rendition of this merick is more or less as given by Carolyn Wells in her *ook of American Limericks* (Putnam's, 1925):

> Said a great congregational preacher
> To a hen, "You're a beautiful creature."
> And the hen, just for that,
> Laid an egg in his hat,
> And thus did the Hen reward Beecher.

But even the inimitable Carolyn, God rest her soul, pparently did not know everything about this specimen, or she includes it among a group of anonymous limer-cks. Anonymous, my eye! It was written, according to my friend the late George Steele Seymour, of Chicago, by his father-in-law, Charles Payne Smith. George has ecorded this fact in the December 1941 issue of the magazine *The Step Ladder,* and I have no reason to doubt him, for he was a good man, even to the point of appreciating and accrediting the literary attainments of his wife's relatives. The version of the Beecher limerick that the Seymours approved is this:

> Said a great Congregational preacher
> To a hen, "You're a wonderful creature!"
> So the fowl, just for that,
> Laid an egg in his hat;
> And thus did the hen reward Beecher.

That seems to make sense, so suppose we let the matter rest there.

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LABORATORY LILY

Tiger lily, blooming bright,
Rooted in vermiculite,
How scientific industry
Is tampering with your chemistry!
And other things have come your way,
Including altered length of day.
For all I know your orange and black
May next be subject to attack;
And when you come to bloom again
You may have leaves like sugar cane,
Or flowers of such supersize
You'll likely win a punkin prize.
They may put zippers on your genes
By methods learned unbuttoning beans,
Or give you scent of new-mown hay—

Yet as I see you here today
You've kept your spots and petals, really,
As well as some wild leopard lily;
Still, here there's tingling force of change
In serried glasstops, range on range,
Where motors make their cyclic switch
And plantsmen give those genes a hitch.
The word comes in through whited roofing
That these geneticists aren't spoofing—
They'll make established lilies cringe,
Accept a plain edge or a fringe.

But for the sake of poetry
Hold fast your Blakeian symmetry,
And in that artificial light
Keep on blooming, blooming bright.

Charles E. Gapen

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ETYMOLOGICAL ITEM

The interesting paper on salt production in the March number of The Scientific Monthly includes an etymological item which I should like to correct. It reads as follows (p. 157, col. 1): "The English place names such as Greenwich, Sandwich, Ipswich, etc. refer to the sites of salt manufacture or trade, for the word *wich* in Anglo-Saxon has that meaning."

In fact, of course, the element *-wich* in these names means 'village, hamlet,' or in some cases 'stronghold, dwelling.' In early times the name element was spelt *-wic,* though probably not different in pronunciation from the modern *-wich.* It is identical with the word *wic,* from Latin *vicus* 'village, hamlet, estate, country seat.' The Latin word was taken into English in prehistoric times, probably before the English migrated from Germany to Britain. In the *Anglo-Saxon Dictionary* of

J. R. Clark Hall (3rd ed., 1931), *wic* is glossed as follows: 'dwelling-place, lodging, habitation, house, mansion, village, town, entrenchments, camp, castle, fortress, street, lane, bay, creek.' It will be noted that none of these meanings shows any connection with salt or its preparation. The *wic* which means 'bay, creek' is a native English word, cognate with Old Norse *vík* 'bay, inlet,' and the editor of the dictionary should not have combined it with *wic* 'house, village' as he has done.

Dr. Wilcox was led astray (naturally enough) by the modern English word *wich*, defined in the *Shorter Oxford English Dictionary* as 'a salt-works, salt-pit, or brine-spring, in the salt-manufacturing district of Cheshire and neighboring parts.' In the plural this word is also used to mean 'the salt-making towns of these parts,' and this plural use can be traced back (in Latin writings) to medieval times, and presumably gave rise to the specialized meaning of the singular of the word. As it happens, several of the salt-manufacturing towns of this particular district have names ending in *-wich,* and in consequence the name element *-wich,* in this part of England (but not elsewhere), eventually became associated with salt-making. The next step was easily taken: this name element was abstracted from the various place names and came to be an independent word, first used only in the plural, in the sense 'towns where salt is made,' but later used in the singular as well, with the meaning 'salt-works' or the like. The new word won currency locally, but has never spread into the language generally.

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A HAIR PERHAPS DIVIDES THE FALSE AND TRUE

SOME of the contributors to your May issue ha reached the conclusion that we have to reshape o moral concepts in view of Dr. Kinsey's findings. T logical conclusion is, of course, that similar investig tions concerning honesty or scientific objectivity wou call for revision of our norms here also.

Fortunately, irrespective of how logical such concl sions may sound, any keen observer of man, of existe tial man, knows that it is *not* in the nature of man *aspire to conform to his present factic reality.* On th contrary: It is an ineradicable characteristic of his n ture to aspire to transcend such reality. That is why me do not give up their ideal of scientific objectivity irr spective of what statistics might have to say on i prevalence.

Man is certainly a chaotic creature, yet also a sy temic creature. The evolutionary potential within ma jots down his present inconformity with his prese factic reality as ethical ideals. Such ideals undoubted result in the fulfilment of some of man's inherent tend encies and in the frustration of others.

Frustration, of course, is not bad in itself. Dr. Ka Menninger is authority for the statement that civiliza tion is the product of frustration. But whether good o bad in its outcome, no Kinsey Report can abolish man' dual nature.

As a reader of your magazine, I am looking forwar to the opportunity of reading in THE SCIENTIFI MONTHLY a criticism of the Kinsey Report from th moral philosopher's angle.

ANA MARÍA O'NEI

Universidad de Puerto Rico

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